BRIEF REVIEW

ELECTROMYOSTIMULATION—A SYSTEMATIC REVIEW OF THE EFFECTS OF DIFFERENT ELECTROMYOSTIMULATION METHODS ON SELECTED STRENGTH PARAMETERS IN TRAINED AND ELITE ATHLETES

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ABSTRACT

Filipovic, A, Kleinöder, H, Dörmann, U, and Mester, J. Electromyostimulation–a systematic review of the effects of different electromyostimulation methods on selected strength parameters in trained and elite athletes. *J Strength Cond Res* 26(9): 2600–2614, 2012–This is the first part of 2 studies that systematically review the current state of research and structure the results of selected electromyostimulation (EMS) studies in a way that makes accurate comparisons possible. This part will focus on the effects of EMS on strength enhancement. On the basis of these results, part 2 will deal with the influence of the training regimen and stimulation parameters on EMS training effectiveness to make recommendations for training control. Out of about 200 studies, 89 trials were selected according to predefined criteria: subject age (<35 years), subject health (unimpaired), EMS type (percutaneous stimulation), and study duration (>7 days). To evaluate these trials, we first defined appropriate categories according to the type of EMS (local or whole body) and type of muscle contraction (isometric, dynamic, isokinetic). Then, we established the most relevant strength parameters for high-performance sports: maximal strength, speed strength, power, jumping and sprinting ability. Unlike former reviews, this study differentiates between 3 categories of subjects based on their level of fitness (untrained subjects, trained subjects, and elite athletes) and on the types of EMS methods used (local, whole-body, combination). Special focus was on trained and elite athletes. Untrained athletes were investigated for comparison purposes. This scientific analysis revealed that EMS is effective for developing physical performance. After a stimulation period of 3–6 weeks, significant gains ($p < 0.05$) were shown in maximal strength (isometric *F*max +58.8%; dynamic *F*max +79.5%), speed strength (eccentric isokinetic *M*max +37.1%; concentric isokinetic *M*max + 41.3%; rate of force development + 74%; force impulse + 29%; *v*max + 19%), and power (+67%). Developing these parameters increases vertical jump height by up to +25% (squat jump +21.4%, countermovement jump +19.2%, drop jump +12%) and improves sprint times by as much as −4.8% in trained and elite athletes. With regard to the level of fitness, the analysis shows that trained and elite athletes, despite their already high level of fitness, are able to significantly enhance their level of strength to same extent as is possible with untrained subjects. The EMS offers a promising alternative to traditional strength training for enhancing the strength parameters and motor abilities described above. Because of the clear-cut advantages in time management, especially when whole-body EMS is used, we can expect this method to see the increasing use in high-performance sports.

KEY WORDS strength training, speed strength, maximal strength, power, jumping ability, sprinting ability, trained athletes

INTRODUCTION

In high-performance field sports, there is a clear trend toward faster game play. As a result, performance levels are constantly increasing among the athletes active in these sports. These developments have significantly influenced strength and sprint requirements and have increased the importance of maximal and speed strength training. Nevertheless, in high-performance sports, it is still difficult to combine a substantial amount of proper training of certain strength abilities with normal training. This is primarily because of the lack of regeneration time. This makes time the determining factor in high-performance training. Systematic use of electromyostimulation (EMS) could shorten the duration of strength training without increasing the number of training sessions per week. Furthermore, EMS training methods could enable even elite athletes to gain

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strength without requiring a general increase in the number of training sessions. In addition, this method could also make it possible to develop certain strength parameters in a highly targeted manner.

The EMS has been used in high-performance training since the studies by Kots and Chwilon (36) in the early seventies. Kots and Chwilon (36) achieved strength gains of +30–40% in trained athletes. However, because of a lack of data, it was not possible to fully reproduce the results (20).

Later studies with elite athletes further revealed positive effects of EMS (5, 15, 21, 41, 42, 45, 56, 71). For example, Maffiuletti et al. (42) showed with elite Volleyball players that applying EMS to the muscle groups of the lower body is able to significantly increase isometric *F*max and vertical jump height by >20%, even after a short period of 4 weeks. Furthermore, Delitto et al. (21) proved that selective EMS training is able to significantly enhance strength gains in elite athletes who have a high level of fitness. In this study, a world-class weightlifter achieved a 20-kg strength gain in dynamic *F*max within 14 weeks. With conventional strength training, achieving such an increase would require an average of 2 years of training (29).

All these studies applied EMS locally with single electrodes to defined muscle groups. With further technical developments, EMS progressed from a local stimulation to a whole-body training method where several muscle groups can be trained simultaneously through an electrode belt- and vest system (e.g., miha bodytec, Augsburg, Germany). This enables the activation of the agonist and the antagonist at the same time. Moreover, athletes are now able to train a full muscle chain and thus train more functionally. According to this and because of the better handling and simplified use, in the past years, more and more coaches and athletes have discovered the potential of a whole-body EMS training. Today whole-body EMS is used in leisure sports and in individual sports and field sports on a high-performance level (e.g., several professional Bundesliga soccer teams [German first Division], world-class table tennis players, professional beach volleyball players, and many others).

Systematic reviews have well documented the influence of EMS on strength qualities (7,22,53,58,63) and the neuromuscular system (67). Bax et al. (7) came to the conclusion that EMS can be an effective modality for increasing the strength of the quadriceps femoris. Furthermore, his data indicate that volitional exercise may be equally or more effective than EMS. In addition, Requena Sánchez et al. (58) found consensus that the strength gains achieved with percutaneus electrostimulation training are similar to but not greater than those induced by voluntary training. Paillard (53) considers a combination of EMS and volitional exercise as optimal technique to improve muscle properties. In this investigation, the combination method induced greater muscular adaptations than volitional muscle contraction. Paillard came to the conclusion that this method optimized the strength qualities or muscle power in healthy subjects more than volitional exercise. Paillard further suggests that EMS alone does not improve intermuscular coordination.

Regarding different types of stimulations, further investigations showed that high-frequency currents activate different adaptations in the muscular system than low-frequency currents do (28). Consequently, high-frequency currents are used for enhancing maximal strength, whereas low-frequency currents are used to develop endurance.

In this review, the selected studies, although collectively concerning the improvement of strength abilities, differed in stimulation patterns and training. More precisely, the studies vary in the type of EMS methods, training regimen, stimulation parameters, subject age and physical condition, group sizes, type of control groups, test designs, and parameters and in the EMS equipment used (EMS device and electrodes). Employing numerous different combinations of traditional training programs in connection with modern stimulation parameters is very complex. All of these varying parameters may influence the study outcome to a different degree and thus need to be structured to compare the results.

Therefore, the objectives of this first article out of our 2 part series are to systematically review the current state of research; to structure the results of selected studies in a way that makes accurate comparisons possible; to suggest a suitable review design that could be used as standard for following investigations; to verify the effectiveness of different EMS methods on selected strength parameters in regard to the subjects' individual level of fitness; to provide recommendations for training control to enhance maximal strength, speed strength, and motor abilities such as jumping and sprinting especially in high-performance sports.

There will be a second review that deals with a combination design of training regimen and stimulation parameters for producing a stimulus that activates strength adaptations of the individuals' muscular system and will give recommendations for implementing EMS effectively for a systematic use in strength training especially in high-performance sports.

METHODS

Search for and Selection of Eligible Studies

For the investigative process, we first concentrated on studies focusing on strength gains in skeletal muscles of healthy subjects with a nonclinical background to filter the number of EMS studies. As a result, about 200 studies were collected that were performed between 1965 and 2008. About 60% of them were found with the help of scientific search engines such as Medline and Pubmed and directly on journal data bases such as JSCR (Keywords: electrical stimulation, EMS, strength training, trained athletes, elite athletes). The other 40% were found through references within these studies.

To maximize the number of comparable randomized controlled trials, certain preconditions were set: (a) *Subjects:* healthy, unimpaired subjects with ≤35 years of age. (b) *Type of stimulation:* percutaneus EMS with the aim of enhancing strength abilities of both the upper and lower body. (c) *Study* *design:* minimum study duration of ≥7 days, comparable tests such as pretests, posttests, and retests.

Only studies with homogeneous groups on a comparable level of fitness were considered in this review. Significant gains for the training group were documented in relation to the baseline and the difference to the control group in posttesting.

Data Classification

The review began by selecting a total of 59 studies. From this pool of investigations, all the trials in which male and female subjects formed different training groups or in which >1 EMS group (with a different EMS method) was trained or tested with different parameters were once again divided into individual trials (cf., e.g [18,54]). For example, studies investigated 2 types of EMS methods, the trials were split, and each was sorted to a specific subgroup (e.g., isometric EMS, combination EMS).

All in all, 89 trials were emphasized from the original 59 studies. These trials were analyzed, compared, and presented in a comprehensive table.

To represent this large number of studies and their results clearly, the trials were classified according to the type of EMS method (local EMS methods–stimulation of defined muscle groups with single electrodes; whole-body EMS methods–stimulation and activation of several muscle groups simultaneously through a electrode belt system, agonist and antagonist are activated at the same time) and type of muscle contraction (e.g., isometric EMS, dynamic EMS [includes isokinetic]). The combination EMS method is a subgroup for both types of stimulation. In combination methods, the types described above are combined with additional specific training (e.g., conventional weight training, plyometric jump training).

Besides these categories, the review primarily differentiated between the subjects' individual levels of fitness: untrained subjects (no experience in strength training, no regular exercise before study); trained subjects (experience in strength training, regularly exercising up to 3 sessions per week); elite athletes (systematically training on a high-performance level >3 sessions per week).

Data Extraction

The results that were relevant for the study are included with the basic parameters. All data are represented in terms of mean values and *SD*. Increases and decreases are expressed as percentages. Here, we have differentiated between pretesting, posttesting, and retesting.

The data from the analyzed studies were sorted and presented in tables. To enable accurate categorization and to provide a layout for evaluating and comparing several different studies at the same time, all the tables were based on the same parameters (cf., Table 1).

Statistical Analyses

To analyze the data, different categories were formed as shown in Figure 1. Within the categories, the assorted studies were put into tables. To compare the results and or point out

Table 1. Overview of data extraction.*

Study			Training regimen				EMS parameters				Intensity	Result posttest
Subjects' level of fitness	Type of EMS method	*n*	Sessions	Study period	Contractions/ session	Sessions/ wk	Impulse frequency	Impulse on time	Impulse interval	Duty cycle	Stimulation intensity %MVC	Strength parameter
Untrained trained elite	Local EMS/WB-EMS isometric dynamic combination	Number of trials per category	Number of sessions	Weeks	Number contractions per session	Sessions/wk	Hz	Contraction time on (s)	Time between 2 single impulses off (s)	Stimulation ratio relation between on and off time	Percentage of MVC	Percent change of the investigated parameter (posttest – pretest)

*EMS = electromyostimulation; WB = whole body; MVC = maximum voluntary contraction.

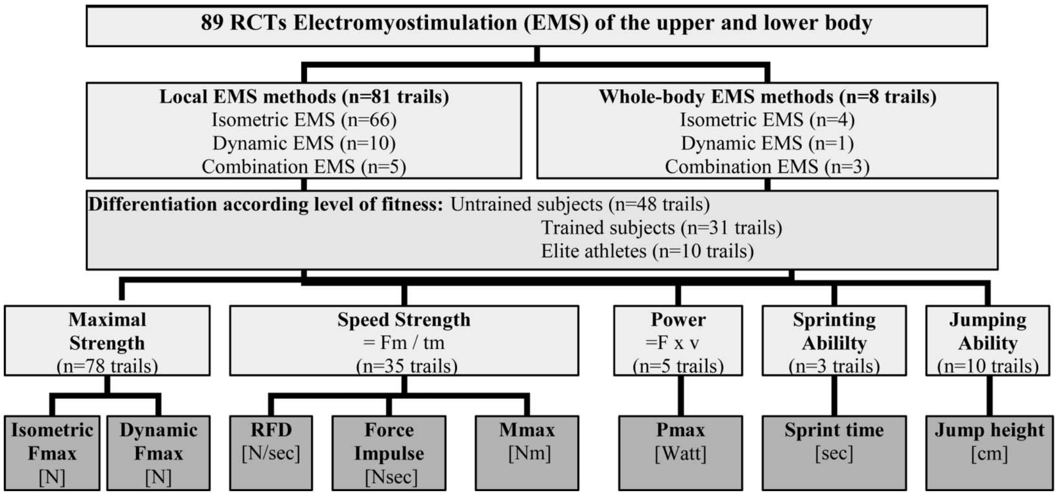

Figure 1. Overall structure of the systematic analysis of 89 selected randomized controlled trials (RCTs) focusing on the electromyostimulation (EMS) of healthy unimpaired subjects.

relationships between certain parameters, extreme data were eliminated. To show the strength variances between pretesting, posttesting, and retesting, all the results have been converted into percentages. In references to significance levels or confidence intervals, an α-level of 0.05 was used, which corresponds to a 95% confidence interval. For correlation comparisons, the level of significance was established at $p \leq 0.05$.

RESULTS OF THE SEARCH AND SELECTION PROCESS

The analysis of the selected studies showed that more than half of the trials tested male subjects. Studies with exclusive female subjects or a mixed sample had a stake of 20%. Only 7 studies did not differentiate with details on gender.

On average, the subjects were 22.8 years old at the time of the pretest for the trials. All the subjects were classified as healthy and unimpaired and had no history of injury in the tested muscle group. The trials covered a period between 10 days and 14 weeks. On average, 10.6 subjects were examined over an average of 5 weeks (cf., Table 2). However, the majority of the studies (68%) contained a stimulation period of 4–6 weeks. The number of training sessions varied from 1 to 7 sessions per week. An average of 16.3 sessions was completed within the training period, with a duration of 17.6 ± 10.7 minutes per session.

Regarding the locality of the stimulated muscles, the analysis showed that the lower body was the main object of the trials (75%). Furthermore, the study showed that the m. quadriceps femoris (60%) was the most examined muscle. In contrast, only 17% of the studies investigated the upper body. Beyond that, only 8% analyzed the effects of whole-body stimulation on the muscle (9,11–13,65).

Besides these basic data, the analysis performed during this study shows that several parameters are used to influence stimulation effectiveness (i.e., the training outcome).

Impulse Type

Analysis of the selected studies revealed a large deviance in the types of EMS stimulators used. A stimulator produced by the company "Compex" was used in 37% of the trials conducted after 1994. Before then, an "Electrostim 180" device was used (28%). In the recent years, new stimulators, such as the "Bodytransformer" or the EMS stimulator manufactured by "Miha Bodytec" have been in use for whole-body EMS.

The impulse type that these EMS stimulators produced in the selected studies was biphasic in 40% of the cases and monophasic in 12%. In 21% of the trials, a so-called "Russian current" was used. This type of impulse was delivered by the "Electrostim 180." An alternating sinus current was applied in only 8% of the studies. Furthermore, only 5% of the trials were accomplished with an Interference or Faraday current. The rest of the studies (15%) provided no information about the impulse type used.

It is noteworthy that, from 1994 onward, most of the trials (67%) used biphasic impulses.

Impulse Form

Forty-eight percent of the impulses were delivered with a square or rectangular form, and another 27% used an alternating sinus impulse form. In 15% of the studies, stimulation was performed with symmetrical, asymmetrical, triangular, and peak impulses. The rest of the trials (10%) did not comment on the impulse form.

Table 2. Overview of the mean values for the training regimen and stimulation parameters.*

89	Training regimen					Impulse width	Stimulation frequency	Impulse intensity	On time	Interval	Stimulation intensity
Trials	Subjects	Age	Sessions	Weeks	Min	(μs)	(Hz)	(mA)	On (s)	Off (s)	%MVC
Mean	10.6	22.9	16.5	5.1	17.7	266.3	68.8	59.6	10.2	42.4	59.5
SD	5.0	2.8	6.8	2.3	10.9	133.0	31.8	32.3	8.0	48.7	25.3

*MVC = maximum voluntary contraction.

Impulse Width

On average, an impulse width of 261 ± 132 microseconds was used. A width between 200 and 400 microseconds was applied in 48% of the study designs. In 27% of the studies, no information about impulse width was provided.

Impulse Frequency

The regulated frequency varied between 25 and 2,500 Hz. Frequencies over 1,000 Hz were not included in the mean value; compare with (18,47,60).

Impulse Intensity

To regulate the maximum impulse intensity, this value was either defined as the maximal tolerated amperage or as the maximal comfortable amperage (milliamperes). This value varied between 10 and 200 mA.

Impulse on Time

In the sample of trials, the time over which a single impulse stimulated a muscle group varied between 3 and 60 seconds (contraction time). The interval between 2 impulses varied between 4 seconds and 3 minutes.

Stimulation Intensity

Intensity was defined and regulated on the basis of the maximum voluntary contraction (MVC) during the retest of a particular muscle and expressed as a percentage. The values ranged between 5 and 112% of the MVC. In 42% of the studies, no information was provided on the intensity in relation to the MVC.

RESULTS OF THE EFFECTS OF ELECTROMYOSTIMULATION ON CURRENT STRENGTH PARAMETERS

The following section summarizes the effects of the local and whole-body EMS methods on the strength parameters discussed below. The results have been summarized and categorized according to 2 main types of strength: maximal strength and speed strength. Furthermore, the results show the development in jumping and sprinting ability and changes in power (defined as the product of force and velocity within the dynamic diagnostic measurements).

In this review, only studies with homogeneous groups on a comparable level of performance were considered. Significant gains for the training group were documented in relation to the baseline and according to the difference to the control group in posttesting.

Effects of Electromyostimulation on Maximal Strength

Isometric Maximal Strength. Regarding the effectiveness of different EMS methods (in particular for isometric EMS), the results showed considerable gains in isometric *F*max of up to +58% in strength-trained subjects (trained) and up to +43% in elite athletes (elite athletes; >40%) (18,19,41,61) (>15%) (17,24,42,50,56,57).

Trials using isometric EMS revealed significant gains of +32.6 ± 17.6% in trained subjects (17–19,24,50,57,62) and of +32 ± 15.6% in elite athletes (41,56). With regard to the level of fitness, the analysis showed that trials with untrained subjects that achieved significant gains in isometric *F*max after isometric EMS revealed a lower average increase in strength gains (+23.5 ± 8.9%) (3, 6, 14, 20, 26, 27, 30, 34, 38–40, 42, 44, 46, 48, 49, 55, 64) than trials with trained subjects and elite athletes demonstrated. The mean strength gains for trials with significant increases are shown in Table 3.

The application of dynamic EMS showed a significant increase of +22% in untrained subjects (33) and +17.4 ± 0.6% in trained subjects (51,57).

The combination of isometric EMS and conventional weight training (combination EMS) made it possible to achieve significant strength increases in the m. quadriceps femoris of up to +62% in untrained (+39.2 ± 32.3) (30,69) and up to +28.5% in elite volleyball players (42). On average, this category showed an increase of 35.6 ± 23.7%. For example, Maffiuletti et al. (42) combined the isometric EMS (3 sessions per week) with an additional plyometric jump training (3 sessions per week) and achieved strength gains within 4 weeks of +28.5% in the m. quadriceps femoris and +25.4% in the m. triceps surae of elite volleyball players; compare with (30).

Compared with the local EMS methods, the whole-body method showed lower increases in isometric *F*max. Speicher et al. (65), who tested trained subjects, achieved an increase of +9% the in m. biceps femoris after dynamic whole-body EMS

Table 3. Overview of increases in isometric maximal strength in posttest.*

Level of fitness	Study		Training regimen			EMS parameters				Intensity	Posttest
	EMS method	*n*	Sessions	Weeks	Sessions/wk	Hz	On (s)	Off (s)	%Duty cycle	%MVC	%Isometric *F*max
Untrained	Isometric	22	19.3 ± 9.4	5.1 ± 1.7	3.7 ± 1.0	57.2 ± 18.6	8.7 ± 4.4	33.6 ± 17.7	26.5 ± 13.7	63.6 ± 16.4	23.5 ± 8.9
Trained	Isometric	8	19.1 ± 4.8	4.6 ± 2.1	4.8 ± 2.0	80 ± 21.6	7.9 ± 4.0	47.1 ± 34.5	19.0 ± 14.1	68.6 ± 27.9	32.6 ± 17.6
Elite	Isometric	2	10.5 ± 2.1	3.5 ± 0.7	3 ± 0	90 ± 14.1	4.5 ± 2.1	18.5 ± 2.1	19 ± 5.7	70 ± 14.1	32 ± 15.6
Untrained	Dynamic	1	24	6	4	50	n.d.	n.d.	50	77.5	22
Trained	Dynamic	2	21 ± 4.2	7 ± 1.4	3 ± 0	80 ± 28.3	5.8 ± 3.0	63.3 ± 49.1	11.2 ± 7.8	87.9	17.4 ± 0.6
Untrained	Isocombination	2	11.5 + 11.5	4.5 ± 0.7	2.5+2.5	85 ± 49.5	9 ± 8.5	45 ± 21.2	14.5 ± 7.8	n.d.	39.2 ± 32.3
Elite	Isocombination	1	12 + 12	4	3 + 3	117.5	3	17	15	60	28.5
Trained	Dynamic-WB	2	8	4	2	85	6	4	60 ± 0	n.d.	9
Trained	Combination WB	2	4+4 ± 0	4	2 ± 0	85	6	4	60 ± 0	n.d.	8

*EMS = electromyostimulation; MVC = maximum voluntary contraction; WB = whole body.

and +8% in the m. quadriceps femoris after dynamic whole-body combination EMS. On the other hand, no significant strength increase was achieved with isometric or isometric combination whole-body EMS; compare with (37,65).

Dynamic Maximal Strength. The strength gains shown in dynamic *F*max varied between +3 and +79.54% (5, 10–13, 21, 36, 47, 65, 69, 71, 72).

Both the dynamic EMS method (+52.9 ± 37.6%) (71,72) and the isometric EMS method (+45.6%) (72) achieved significant strength increases in dynamic *F*max in trained and elite athletes. For example, Willoughby and Simpson (72) achieved strength gains in dynamic *F*max (1RM) of +45.6% in the m. quadriceps femoris of trained female subjects within 6 weeks of isometric EMS (3 sessions per week). Another stimulation group (trained female subjects) were trained with dynamic EMS with the same parameters. In posttesting, Willoughby and Simpson also showed an increase of the dynamic *F*max of +79.54% in the m. quadriceps femoris.

Despite the already high level of fitness of elite athletes, it was possible to verify high strength gains in dynamic *F*max with isometric EMS (+34.1 ± 21.7% [5,21,36,71]) and dynamic EMS (+26.3% [71]). Regarding the lower body muscles, both methods showed strength gains in the m. quadriceps femoris and m. triceps surae of >+50% (21,36,72). For this reason, the systematic performance training conducted in parallel with the simulation period showed positive effects on strength adaptation. This could also be seen in elite athletes enhancing isometric *F*max.

In comparison with these results, Venable (69) also achieved significant strength gains in dynamic *F*max of +20.7% in the m. quadriceps femoris after 5 weeks of combination EMS. Venable stimulated untrained subjects by combining isometric EMS (3 sessions per week) and additional conventional dynamic weight training (3 sessions per week per 5 sets per 10 reps). However, because of a lack of comparable studies in this area, the study by Venable (69) is not well suited for comparisons with the results of previous investigations.

Compared with the results achieved with local EMS methods, whole-body EMS methods only showed minor strength gains (<15%) (10–13,65). In the studies by Boeck-Behrens (12,13), trained athletes were stimulated with isometric whole-body EMS. Only in these 2 studies did the subjects show comparable significant strength gains in dynamic *F*max between 10 and 14.73% (m. triceps brachii). In contrast, the whole-body combination EMS methods only resulted in strength gains of 6–10% (cf., Table 4).

Effects of Electromyostimulation on Speed Strength

Speed strength is the most important of the central strength abilities in modern high-performance sports. Speed strength is the ability of the neuromuscular system to exert maximal forces (F_m) in minimal time (t_m) within a given movement (Speed Strength index $= F_m/t_m$ [F_m = peak force, t_m = time to peak force]) (16,31,35,75).

Table 4. Overview of increases in dynamic maximal strength in posttest.*

Study			Training regimen				EMS parameters				Intensity	Posttest
Level of fitness	EMS method	*n*	Sessions	Weeks	Contractions	Sessions/wk	Hz	On (s)	Off (s)	%Duty cycle	%MVC	%Dynamic *F*max
Trained	Isometric	2	18	6	n.d.	3	50	25	180	12.2	n.d.	45
Elite	Isometric	4	19 ± 3.5	9.1 ± 6	16.5 ± 13	3.8 ± 2.2	68 ± 23.9	14 ± 11	91.3 ± 73.5	17.2 ± 8.0	76.8 ± 27.7	31.6 ± 18.8
Trained	Dynamic	1	18	6	3 Sets	3	50	25	180	12.2	n.d.	79.54
Elite	Dynamic	1	18	6	3 Sets	3	50	30	120	20	85	26.3
Trained	WB	10	12 ± 0	6 ± 0	13.8 ± 7.1	2 ± 0	80 ± 0	4.9 ± 1.7	4.9 ± 2.2	45.7 ± 8.6	n.d.	8.1 ± 3.9
Trained	WB combi iso	6	6 + 6 ± 0	6 ± 0	45	2 ± 0	80 ± 0	8 ± 0	4 ± 0	66.7 ± 0	n.d..	10
Elite	WB combi dyn	2	4 + 4 ± 0	4 ± 0	n.d.	2 ± 0	85 ± 0	60 ± 0	60 ± 0	50 ± 0	n.d.	8.5 ± 0.7

*EMS = electromyostimulation; MVC = maximum voluntary contraction; WB = whole body.

This ability is required in many sports that are characterized by explosive movements with maximal forces like, for example, sprinting, jumping, and throwing in athletic or team sports, snatch, clean and jerk in weightlifting, throwing in judo, or punching in boxing; compare with (31).

When it comes to an athlete's ability to move a defined weight as fast as possible, the analysis showed that EMS is able to significantly develop the maximal velocity (*v*max) on a fixed weight and, in turn, increases the isokinetic strength (*M*max) for a certain angle velocity (degrees per second).

Maximal Torque Production Related to Certain Angular Velocities (Isokinetic Mmax). To present the data, the results in isokinetic *M*max were divided into strength gains for eccentric and concentric movements. Regarding the isokinetic *M*max in particular, the studies that applied isometric EMS and dynamic EMS revealed the effectiveness of EMS in developing the isokinetic *M*max (4, 8, 20, 25, 32, 33, 38, 39, 46, 51, 57, 73). The analysis showed that both methods can significantly increase the eccentric and concentric isokinetic *M*max. Furthermore, it was shown that after dynamic EMS, overall, higher gains were achieved in eccentric (+28.4 ± 7.4% in $-60°{\cdot}s^{-1}$ and +27.0 ± 11.2% in $-120°{\cdot}s^{-1}$) than in concentric isokinetic *M*max (+28.2 ± 18.6% in $60°{\cdot}s^{-1}$, +15.0 ± 0% in $120°{\cdot}s^{-1}$, and +21.2 ± 15.3% in $180°{\cdot}s^{-1}$) of elite athletes (5, 15, 41, 56) (cf., Tables 5 and 6). After stimulation, the m. quadriceps femoris in particular showed higher strength gains for eccentric movement than for concentric movements. In turn, even dynamic EMS applied during eccentric movement showed positive effects for enhancing concentric isokinetic *M*max.

With combination methods, Dervisevic et al (23) achieved significant gains in isokinetic *M*max (+15.8% in $30°{\cdot}s^{-1}$, +24% in $60°{\cdot}s^{-1}$, and +29.8% in $180°{\cdot}s^{-1}$) in the m. quadriceps femoris of trained subjects after a stimulation period of 10 weeks. They combined isometric EMS (3 sessions per week) with conventional hypertrophy weight training (3 sessions per 5 sets per 5 reps). Although they achieved significant strength gains, the results are limited in their suitability for comparison because of a lack of trials in this area.

Overall, the analysis of strength gains after isometric EMS for each of the fitness level categories showed that it was possible to verify higher strength gains for elite athletes (+20.5 ± 11.5% [5,15,41,56]) than for trained (+14.1 ± 4.6% [19,23,24,57]) and untrained subjects (+18.9 ± 9% [8,20,39,46,60]) (cf., Table 5).

The analysis yielded useful results in regard to the strength gains made in connection with certain angular velocities. It showed that this method can be particularly effective for developing the higher concentric angular velocities that are important in explosive movements. For example in the study by Maffiuletti et al. (41) in which 20 elite basketball players were trained 3 times a week with isometric EMS over a stimulation period of 4 weeks in parallel with their usual training. The results of the posttest showed significant increases (+37% in

TABLE 5. Overview of increases in isokinetic *M*max in certain concentric angular velocities in posttest.*

Study			Training regimen				EMS parameters				Intensity	*M*max concentric		
Level of fitness	EMS meth	*n*	Sessions	Weeks	Contractions	Sessions/wk	Hz	On (s)	Off (s)	%Duty cycle	%MVC	$60° \cdot s^{-1}$	$120° \cdot s^{-1}$	$180° \cdot s^{-1}$
Untrained	Iso	7	14.6 ± 1.1	3.5 ± 0.8	n.d.	4.3 ± 1	63.3 ± 15.1	8.6 ± 4.8	25.6 ± 23.1	34.2 ± 14.9	61.1 ± 15.3	20.9 ± 8.9	17.5 ± 5.8	22.6 ± 19
Trained	Iso	4	22.5 ± 6.2	7.3 ± 2.5	15.3 ± 12.9	3.3 ± 0.5	126.7 ± 64.3	6.3 ± 3.5	28 ± 31.1	33.4 ± 23.5	54.2 ± 39.9	10.4 ± 0.9	14	16.4 ± 7.4
Elite	Iso	4	13.5 ± 7.1	4 ± 1.4	35.3 ± 9.3	3 ± 0	91.2 ± 10.3	4.5 ± 1.3	18 ± 2.4	19.9 ± 4.8	58.8 ± 2.5	28.2 ± 18.6	15 ± 0	21.2 ± 15.3
Trained	Dyn	4	14.5 ± 7.9	5.5 ± 1.9	22 ± 9.8	2.5 ± 0.6	65 ± 21.9	6.5 ± 4.9	50 ± 0	11.2 ± 7.8	87.9		16.8 ± 2.5	16.8 ± 14.7
Elite	Dyn	1	24	6	5 Sets	4	75	n.d.	n.d.	n.d.	30		20	
Trained	Comb	1	30 + 30	10	n.d.	6	n.d.	n.d.	n.d.	n.d.	10	15.8	24	29.8

*EMS = electromyostimulation; MVC = maximum voluntary contraction.

TABLE 6. Overview of increases in isokinetic *M*max in certain eccentric angular velocities in posttest.*

Study			Training regimen				EMS parameters				Intensity	*M*max eccentric	
Level of fitness	EMS method	*n*	Sessions	Weeks	Contractions	Sessions/wk	Hz	On (s)	Off (s)	%Duty cycle	%MVC	$60° \cdot s^{-1}$	$120° \cdot s^{-1}$
Elite	Isometric	4	13.5 ± 7.1	4 ± 1.4	35.3 ± 9.3	3 ± 0	91.2 ± 10.3	4.5 ± 1.3	18 ± 2.4	19.9 ± 4.8	58.8 ± 2.5	28.2 ± 7.4	27 ± 11.2
Untrained	Dynamic	2	24 ± 0	6 ± 0	35.5 ± 0.7	4 ± 0	50 ± 0	n.d.	n.d.	50 ± 0	93.8 ± 23	36 ± 0	

*EMS = electromyostimulation; MVC = maximum voluntary contraction.

$60^\circ\cdot s^{-1}$; +29% in $120^\circ\cdot s^{-1}$) for all tested eccentric angular velocities. Under concentric conditions, in particular the middle and especially the higher velocities showed significant increases in isokinetic *M*max (+32% in $180^\circ\cdot s^{-1}$; +30% in $240^\circ\cdot s^{-1}$; +36% in $300^\circ\cdot s^{-1}$; and +43% in $360^\circ\cdot s^{-1}$).

The investigation of the dynamic EMS was not able to show differences or advantages in the effectiveness for enhancing isokinetic *M*max between dynamic and isokinetic training movements during the stimulation (cf. [4, 32, 33, 51, 57, 73]). Both methods achieved strength gains in concentric and eccentric isok *M*max of >20% for both trained and elite athletes. Also, in comparison to the isometric EMS, it was not possible to point out any significant difference in effectiveness.

No trials have investigated the effects on isokinetic *M*max when using whole-body EMS methods.

Explosive Force Production (Rate of Force Development) and Starting Force (Force Impulse). The rate of force development (RFD) and starting force (force impulse) are the essential components of speed strength. The RFD manifests itself in the steepness of the force boost within the isometric strength diagnostics. The force impulse describes the force produced in the first moment of a muscular effort (isometric). These parameters were only examined in trials for whole-body EMS.

The study conducted by Schmithüsen (61) and Speicher et al. (65) was able to show a significant increase in RFD and force impulse for several muscle groups. In particular, the isometric and combination methods for whole-body EMS were seen to influence enhancement of the strength parameters that were tested.

In posttesting, Schmithüsen (61) was able to show a significant increase of up to +58% in the maximal RFD for the upper body after 4 weeks. Regarding the increments of different time sections, Schmithüsen (61) was able to show that the RFD in particular develops in the early time sections of force production. Schmithüsen combined isometric whole-body EMS (1 session per week) with conventional isometric strength training (1 session per week).

Similar results were also shown in the production of force impulses. Schmithüsen (61) found significant increases of up to 20% in the upper body and demonstrated the particular development of the early time sections.

Regarding the lower body, Speicher et al. (65) demonstrated significant increases up to 16% in the m. quadriceps femoris of the early time sections. No significant increases were shown in maximal RFD. Speicher et al. (65) investigated the effect of dynamic whole-body combination EMS. They combined dynamic EMS (1 session per week) with dynamic weight training (1 session per week).

Regarding changes in the force impulse, Speicher et al. (65) showed increases of up to +29% in the early time sections.

In particular, the whole-body combination EMS methods seem to have a positive effect on enhancing explosive force and starting force parameters. Furthermore, with regard to the contraction speed, the study by Speicher et al. (65) was able to show increases in *v*max of +19% in the m. biceps femoris during posttesting of trained subjects after dynamic whole-body EMS. After 2 weeks of training, the *v*max increased another +2% in retesting. No significant gains in *v*max were found during posttesting in the m. quadriceps femoris.

Despite the lack of trials for comparison, the results from Speicher et al. (65) and Schmithüsen (61) suggest that the whole-body EMS methods have a positive influence and can be effective for developing speed strength and explicitly and significantly enhances the force boost in the starting moments (65) (cf., Table 7).

Although research is still open in some fields, these results are very interesting for today's high-performance sports because of their clear connection to sprint and jump performance. These results build the basis and increase the interest of the following studies.

Effects of Electromyostimulation on Jumping and Sprinting Ability

Vertical Jumping Ability. For jumping ability, the analysis showed increases from +2.3 to + 19.2% after isometric EMS (+10 ± 6.5%) (5, 36, 41, 45, 54 , 72), +25.28% after dynamic

Table 7. Overview of increasing in explosive force (RFD) and starting force (impulse) in posttest of trained subjects.*

		Training regimen				EMS parameters				Intensity	RFD (ms)		Impulse (ms)	
WB-EMS method	*n*	Sessions	Weeks	ses/wk	Muscle	Hz	On (s)	Off (s)	%Duty cycle	%MVC	Max	100–200	100	200–500
Isometric	1	8	4	2	Abs	85	60	60	50	n.d.	14		20	
Dynamic	1	8	4	2	QF	85	60	60	50	n.d.	n.d.	n.d.		11
Iso Combination	1	4 + 4	4	1 + 1	ES	85	60	60	50	n.d.	58	68 ± 8.5		18.5 ± 2.1
Dyn combination	1	4 + 4	4	1 + 1	QF	85	60	60	50	n.d.	#	16		23.5 ± 7.7

*RFD = rate of force development; EMS = electromyostimulation.

EMS (72), and results varying from +6.7 up to +21.4% after combination EMS (+11.2 ± 5.5%) (30,42,69).

The whole-body methods, however, were not able to achieve significant gains in jumping ability in the posttest phase (61) (cf., Table 8).

With regard to specific types of vertical jumps, the analysis showed that isometric EMS significantly enhanced squat jump (SJ) by +11.3 ± 1.9% in trained subjects and elite athletes (5,41,54). It also enhanced countermovement jumps (CMJs) by +19.2% (36) and drop jumps (DJs) by +6.6% in elite athletes (5). The use of dynamic EMS resulted in increases of +25.28% in trained women (72).

For combination methods, the analysis showed significant strength gains of +15.3±11% in SJ (+7.5% in untrained [30] and +21.4% elite athletes [42]), +8.7±2.9% in CMJ (+6.7% [30] and +7.5% [69] in untrained subjects and +12% in elite athletes [42]) and +12% in DJ of elite athletes (42).

Regarding these enhancements, the analysis showed that isometric EMS and isometric combination EMS in particular achieved relatively balanced gains for SJs, CMJs, and DJs. With both methods, Maffiuletti et al. (41,42) achieved significant gains in SJs of >+17% with elite athletes. The high increases in CMJ results after dynamic EMS must be viewed critically because of the lack of comparison data. However, the results show that it was possible to increase vertical jumps by >25% for trained female subjects after 6 weeks of dynamic stimulation (dynamic EMS) of the m. quadriceps femoris (72).

As mentioned above, speed strength is one of the main factors influencing jumping and sprinting ability. However, the analysis was not able to show a correlation between dynamic *F*max and vertical jump heights because of a lack of investigations. On the other hand, the study performed by Maffiuletti et al. (41) with elite basketball players was able to demonstrate a significant relation ($r = 0.647$; $\alpha < 0.05$) between isometric *F*max of the m. quadriceps femoris at an angle of 115° and jumping heights for SJs. On average, elite players showed strength gains in isometric *F*max of +43%, and they were able to enhance their SJ height by +14%.

The analysis showed that combining isometric EMS with plyometric jump training seems to have a particularly positive influence on the possibilities for developing vertical jumping ability (30,42). As with the investigation results for the previous points, the additional training conducted in parallel with the stimulation showed positive effects on jumping ability despite the fact that the training duration in general is significantly higher. Although the elite players that trained up to 8 sessions per week, combination EMS does not seem to overstress the muscular system. In turn, the additional motor training conducted in parallel with stimulation in conjunction with the higher training duration seems to improve jumping ability. This is particularly the case for the type of jumps that characterize sports like basketball and volleyball. Furthermore, the analysis showed that in particular elite athletes who already had a high level of jumping ability achieved significant gains.

Table 8. Overview of increasing in vertical jump height in posttest.*

Study			Training regimen					Intensity	Posttest % jump high		
Level of fitness	EMS method	*n*	Sessions	Weeks	Contractions	Sessions/wk	Minutes	%MVC	SJ	CMJ	DJ
Trained/elite	Isometric	4	15.3 ± 2.2	4.4 ± 1.3	31.3 ± 15	4.0 ± 1.7	13.3 ± 2.4	55 ± 4.1	11.3 ± 1.9	19.2	6.6
Trained	Dynamic	1	18	6	30	3	n.d.	n.d.		25.28	
Untrained	Combination	2	11.5 + 11.5	4.5 ± 0.7	31.5 ± 30.4	5 ± 1.4	23 ± 15.6	71.5	7.5	7.1 ± 0.6	
Elite	Combination	1	12 + 12	4	39	6	26	60	21.4	12	12
Trained	Whole body	2	4 + 4 ± 0	4 ± 0	30 ± 0	2 ± 0	n.d.	n.d.		0	

*SJ = squat jump; CMJ = countermovement jump; DJ = drop jump; EMS = electromyostimulation; MVC = maximum voluntary contraction.

Sprinting Ability. The studies analyzed in this area showed improvements within 3 weeks of –3.1 ± 1.7 in elite athletes. Brocherie et al. (15) reduced the 10-m sprint time of elite ice hockey players by −4.8% and Pichon et al (56) improved the 25-m time (with pull-buoy) by −1.3% and the 50-m freestyle by –1.45. Both studies used isometric EMS over a stimulation period of 3 weeks (3 sessions per week) for enhancing the most relevant muscle group for the test challenge (m. quadriceps femoris and m. latissimus dorsi).

With combination EMS, Herrero et al. (30) achieved a reduction of 20-m sprint time by −2.3% in untrained subjects after combining isometric EMS (2 sessions per week) with plyometric jump training (2 sessions per week) after 4 weeks of stimulation (cf., Table 9).

Table 9. Overview of time reduction in short sprint ability in posttest.*

Level of fitness	Study		Training regimen					EMS parameters				Intensity	Posttest
	EMS method	*n*	Sessions	Weeks	Contractions	Sessions/wk	Min	Hz	On (s)	Off (s)	%Duty cycle	%MVC	Sprint%
Elite	Isometric	2	9 ± 0	3 ± 0	20.4 ± 4.3	3 ± 0	12 ± 0	82.5 ± 2.5	5 ± 1	20 ± 0	19.9 ± 3.1	60 ± 0	−3.1 ± 1.7
Untrained	Combination	1	8 + 8	4	53	4	34	120	3	30	9	n.d.	−2.3

*EMS = electromyostimulation; MVC = maximum voluntary contraction.

Effects of Electromyostimulation on Power

As shown in the previous chapter, speed strength manifests itself in a muscle's enhanced ability to achieve maximal contraction or to move a certain weight as fast as possible. Much as with the research performed in the area of explosive force production, only limited data were analyzed. All of the studies investigated the effects of whole-body EMS on trained subjects (37,61,65) (cf., Table 10) and defined the maximal power (*P*max) within the dynamic diagnostic (*P*max = *F*max × *v*max [watts]).

When using isometric whole-body EMS, Kreuzer et al. (37) achieved strength gains in *P*max of +67% in posttesting of the m. rectus abdominis. On the other hand, no significant strength gains were found in the other test muscles (upper body).

Using dynamic whole-body EMS on the lower body (m. quadriceps femoris and m. biceps femoris), Speicher et al. (65) were also unable to achieve any significant strength gains in posttesting. However, after a detrain period of 2 weeks, both muscle groups showed significant development in *P*max using an additional test weight of 40% 1RM (+13% in m. quadriceps femoris and +29% in m. biceps femoris).

For whole-body combination EMS methods, all studies achieved significant gains in *P*max. Kreuzer et al. showed increases of up to 43.49% in the m. rectus abdominis after combining isometric whole-body EMS (1 sessions per week) with conventional isometric strength training (1 sessions per week). In contrast, Speicher et al. only achieved significant increases in *P*max of +12% during retesting in the m. biceps femoris, whereas no increases were found in posttesting. Speicher et al. (65) combined dynamic whole-body EMS (1 session per week) with a conventional hypertrophy strength training (1 session per week).

The results from several studies show that the increase in *P*max went hand in hand with an enhancement in *v*max and maximal strength (65,69). As mentioned above, *P*max is the product of force and speed. Consequently, *P*max can be increased by developing at least 1 of these 2 factors. Although Speicher et al. were only able to show minor increases in dynamic *F*max of the m. quadriceps femoris and m. biceps femoris, *P*max was significantly enhanced after whole-body

Table 10. Overview of increasing in *P*max in post and retest of trained subjects.*

WB-EMS method	*n*	Training regimen Sessions	Weeks	Sessions/wk	Muscle	EMS parameters Hz	On (s)	Off (s)	%Duty cycle	Posttest %W	Retest %W
Isometric	1	8	4	2	Abs	85	4	4	50	67	61.4
Dynamic	1	8 ± 0	4 ± 0	2 ± 0	BF/QF	85 ± 0	60 ± 0	60 ± 0	50	#	21 ± 11.3
Iso combination	2	4 + 4 ± 0	4 ± 0	1 + 1 ± 0	Abs	85 ± 0	4 ± 0	4 ± 0	50	28.5 ± 21.1	36.5 ± 13.5
Dyn combination	1	4 + 4	4	1 + 1	BF	85	60	60	50	#	12

*EMS = electromyostimulation; BF = m. biceps femoris; QF = m. quadriceps femoris.

dynamic EMS (+13% m. quadriceps femoris and +29% m. biceps femoris) because of a remarkable increase in *v*max of up to +21%. This development can be seen in a shifting of the strength-time curve, which is the determining factor for developing speed strength. It has to be said that the m. biceps femoris was under less load than the m. quadriceps femoris within the dynamic movement. Despite bearing less load, in particular the m. biceps femoris achieved much higher increases in *P*max. These results suggest that dynamic movement is not the decisive factor enabling the increase.

In summary, the analysis pointed out that an increase in *P*max can be achieved with all whole-body EMS methods analyzed in this category (cf., Table 10). However, the results are limited, because they are related to individual muscle groups, and the current state of research on whole-body EMS is still open in some areas.

Discussion

Because of the rising requirements in high-performance sports, strength has become a limiting factor in performance. Particularly power and speed strength have increased in importance because of the clear connection to sprint and jump performance.

The present analysis showed that EMS methods are effective for enhancing maximal strength, speed strength, and power in trained and elite athletes and thus are able to increase jumping and sprinting ability.

In regard to different EMS methods, local combination EMS (isometric/dynamic EMS plus conventional strength training) showed similar gains in maximal strength compared with local EMS training alone. In combination EMS, the higher number of training sessions could have overloaded the muscular system of untrained subjects.

The comparison of conventional strength training and combination EMS showed that both methods are able to significantly enhance strength abilities. With respect to the results we cannot state that combination EMS is more effective than conventional strength training (cf. [58]). Only few data are available, which makes accurate evaluation difficult.

In comparison with local EMS methods, whole-body EMS methods achieved lower gains in maximal strength (<15%) within the same period (2 sessions per week). Regarding the parameters of speed strength and power, whole-body EMS methods achieved remarkable gains in RFD and force impulse. However, in the area of whole-body EMS, only few international studies are published, and therefore, the results have to be considered with caution.

Concerning speed strength, it was possible to show that EMS significantly increases speed strength at fix velocities (isokinetic *M*max) in trained and elite athletes. Furthermore, the analysis revealed that the *M*max especially developed well in higher eccentric and concentric angular velocities. This effect might be explained by neuronal adaptations that result in an increased activation of the fast-twitch fibers (19, 21, 41, 42, 43, 56, 71, 72). Several authors see the preferential activation of the large motor units of the type-II fibers with EMS as the main factor for increasing the eccentric and the fast concentric movements (19, 33, 41, 42, 56, 71).

Besides increasing force at higher velocities, EMS was able to enhance the movement velocity in general (*v*max). Particularly dynamic whole-body EMS showed significant increases in *v*max for dynamic movements with an additional weight (40% 1RM) in the m. biceps femoris of trained subjects (61,65). The analysis of the whole-body studies further showed significant gains in RFD and force impulse. Similar to the development in *M*max, whole-body EMS especially enhanced the time sections <200 milliseconds during the production of maximal isometric force (isometric *F*max).

Because of the close relation of speed strength to sprint and jump performance, the analysis showed strong increases in vertical jumping heights of >20% (SJ, CMJ, DJ) in elite athletes (e.g., in elite basketball and volleyball players). Further, we found improvement of up to –4.8% in sprint time for short sprints (e.g., in elite ice hockey players and elite swimmers).

According to the Hill curve, the lower an object's weight, the faster it can be moved. An increase of *v*max at 80 kg would result in a faster movement of an athlete's body weight, which would again positively influence jumping and cyclic sprint movements. Regarding the whole-body methods no significant gains in jumping ability were documented in the posttest phase. Compared with local EMS methods, these studies achieved lower strength gains in dynamic *F*max for the m. quadriceps femoris. Research studies have shown that the strength level of the m. quadriceps femoris and the m. triceps surae influence jumping and sprinting movements (cf. [70]. Nuzzo et al. [52]) assume that on increasing the *F*max the relation between power and the moved bodyweight will be optimized, which again results in the enhancement of the jump height.

With regard to the level of fitness, the analysis showed that trials with untrained subjects that achieved significant gains in isometric *F*max after isometric EMS revealed a lower average increase in strength gains than trials with trained subjects and elite athletes demonstrated.

This effect was unexpected. Untrained subjects are able to increase their strength level with a wide variety in training patterns, whereas elite athletes only have small improvement reserves. However, compared with trained and elite athletes, untrained subjects show less quality in intramuscular and intermuscular coordination, which in turn makes it difficult to transfer the gained strength into the test movement. Furthermore, for untrained subjects it might be difficult to coordinate a mechanical and electrical stimulation at the same time. Because of their training experience trained subjects and elite athletes might be able to better combine both stimuli and thus are able to train more effectively. Moreover, the training load and number of training sessions might have overstressed the muscular system of some untrained subjects, thus hampering strength adaptations. Because in many studies medical parameters such as hormones and blood parameters are lacking, it is not clear if the training load (number of training sessions, stimulation intensity) of some training designs was too intensive for untrained subjects.

Especially typical elements of high-performance training conducted in parallel with EMS training–such as additional weight training, plyometric jumping, or sprinting training, have a positive effect on strength enhancement, motor control, and coordination (74). Accordingly, elite athletes show a higher intermuscular and intramuscular coordination and therefore a more efficient neuromuscular activation and recruitment.

Regarding the strength transfer into physical performance, several studies showed that particularly complex movements–such as CMJs–depend on programmed central recruitment patterns (cf. [9,66]). Compared with voluntary muscle contraction, EMS activates muscle contraction artificially. Consequently, muscle activation by EMS differs from normal physiological muscle activation triggered by the central nervous system. Several authors see the main difference in the fact that the order of motor unit recruitment is not the same with EMS (cf. [1,43,68]).

According to this, we suppose that muscle activation through the electrical stimulus cannot sufficiently be included in recruitment design of dynamic movements and especially jumping movements. Requena Sánchez et al. (58) are of the opinion that additional motor training can integrate the enhanced force into the recruitment pattern (cf. [53]). Our analysis showed that employing dynamic movements within the EMS training alone cannot ensure this integration.

For this investigation, the selected studies were found with the help of current scientific search engines (e.g., Pubmed, Medline) and literature bases (e.g., JSCR). The studies were selected and sorted according to defined criteria. On the basis of these investigated studies, this systematic review documented the effect of EMS and indicated research aspects that are not fully investigated yet. As a result, the study revealed that the research in EMS is still open in some fields. On the basis of these results, this study increases the interest and builds the basis for the following investigations.

PRACTICAL APPLICATIONS

As a modern training method, EMS training represents a promising alternative to traditional strength training for systematically enhancing strength parameters and motor abilities. This study shows that all of the EMS methods analyzed can be effective for significantly enhancing maximal strength and speed strength and jumping and sprinting ability and power. The following recommendations or guidelines should help coaches and athletes to implement EMS effectively for a systematic use in strength training especially in high-performance sports.

The differentiation between the subjects' individual levels of fitness showed that trained and elite athletes in particular are able to enhance their already high level of fitness significantly, even after a short period of time.

Regarding different EMS methods, the results show that trained and elite athletes should focus on isometric EMS when enhancing maximal isometric strength. To develop maximal dynamic strength, EMS should be applied with dynamic movements and combined with additional dynamic maximal strength training. To boost speed strength, coaches and athletes should focus on using faster concentric movements within the training movement in dynamic EMS. To enhance jumping and sprinting ability, dynamic EMS should be combined with additional athletic (speed, agility and quickness training) or plyometric jump training to better transfer strength gains into the movement.

The present review shows that EMS training is able to significantly enhance the most important components of the athletes' performance such as maximal strength and speed strength in the form of explosive movements with maximal forces like, for example, jumping, sprinting, or throwing. To pave the way for systematic implementation, our following-up study will deal with the influence of the training regimen and stimulation parameters on effectiveness. Building on the results from this study, our second study will recommend detailed relevant parameters for training regimens and stimulation to control the training outcome and to systematically implement EMS in today's high-performance training.

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