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Electromyostimulation and Plyometric Training Effects on Jumping and Sprint Time

Abstract

This study compared the effects of four-week training periods of electromyostimulation (EMS), plyometric training (P), or combined EMS and P training of the knee extensor muscles on 20 m sprint time (ST), jumping ability (Squat jump [SJ] and Countermovement jump [CMJ]), maximal isometric strength (MVC), and muscle cross-sectional area (CSA). Forty subjects were randomly assigned to one of the four treatment groups: electromyostimulation (EG), plyometric (PG), combined EMG, and P (EPG), that took place 4 times per week, and a control group (CG). Subjects were tested before and after the training program, as well as once more after 2 wk of detraining. A significant improvement ($p < 0.05$) in ST was observed after training (2.4%) in EG while a significant slowing ($p < 0.05$) was observed (– 2.3%) in EPG. Significant increases in EPG ($p < 0.05$) were observed in SJ (7.5%) and CMJ (7.3%) after training, while no significant changes in both jumps were observed after training and detraining for EG. A significant increase ($p < 0.05$) in MVC was observed after training (9.1%) and after detraining (8.1%) in EG. A significant increase ($p < 0.05$) in MVC was observed after training (16.3%) in EPG. A significant increase ($p < 0.01$) in CSA was observed after training in EG (9.0%) and in EPG (7.1%). EMS combined with plyometric training increased the jumping height and sprint run in physically active men. In addition, EMS alone or EMS combined with plyometric training leads to increase maximal strength and to some hypertrophy of trained muscles. However, EMS training alone did not result in any improvement in jumping explosive strength development or even interfered in sprint run.

Key words
Maximal strength · hypertrophy · countermovement jump · resistance training

Introduction

Short-term programs of electromyostimulation (EMS) are becoming recognized as an effective strategy to develop neuromuscular performance, but results are conflicting. Such studies have found that there is an increase after several weeks of EMS [4,8,18,21,24], no change [7,26,30] or even decrease [25] in maximal voluntary strength of the lower extremity muscles, mainly during open kinetic chain efforts. These discrepancies in the results may be related to: 1) differences in EMS training protocols (i.e. number of sets and repetitions, frequency of stimulation, twitch and rest periods), 2) pretraining status of the subjects, and 3) specificity of the tests to detect changes after EMS training [11,16]. Few studies have examined the effects of EMS-training-induced adaptations on closed kinetic explosive type of movements, such as vertical jumps. To the authors' knowledge, Maffiuleti and coworkers [18,19] reported that 4 weeks of pure EMS training, or combined with plyometric training, signifi-

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cantly improved jumping performance in basketball and volleyball players. However, no study has evaluated the potential advantage of using EMS training during a more specific performance such as 20 m acceleration.

Coaches and researchers in the field of resistance training attempt to identify the most appropriate training stimulus that maximizes power performance enhancement, such as vertical jump or maximal acceleration. Due to the relatively high degree of task specificity involved in movement adaptation and force-velocity characteristics [15], ballistic training [23], plyometric training [1], and Olympic-style weightlifting training [12,17] have resulted in significant vertical jump increases. In addition, a combined training method (e.g. ballistic training and barbell classical resistance training) has also been proven useful to enhance muscle power in a wide variety of maximal jumping, throwing, and running athletic performances [1,5,12,17,23]. However, it remains to be seen whether EMS training protocols could be used as a complementary training method to enhance explosive athletic performance. Only one study has examined whether combined EMS and plyometric training had an effect on vertical jump performance [19]. These authors reported that 4 weeks of combined EMS and plyometric training significantly improved jumping performance in comparison to a control group of volleyball players. All previous studies with team sports have used a time-series study design during pre-season preparation, with a volleyball training group serving as their own control. Unfortunately, no study has examined the single and combined effects of EMS and plyometric training on explosive performance in order to determine the effects of combined EMS and plyometric training on explosive athletic performance. One could therefore hypothesize that combining these two methods would facilitate the improvement in maximal acceleration and jumping ability. The purpose of this study was to compare the effects of 4-week training period of four days per week of electrostimulation training alone, two times per week of plyometric training alone, and two times per week electrostimulation combined with two times per week of plyometric training on anaerobic power and isometric muscle strength in able-bodied individuals. A secondary aim was to estimate the CSA of the trained muscles, since there is effectively a lack of information on muscle changes following EMS training programs.

Material and Methods

Subjects

Forty male physical education students volunteered to participate in the study. Each subject gave written informed consent to participate, with the risks and benefits of the study carefully explained to them prior to its initiation. Thereafter, the subjects signed a written consent form before participation in the study. During the experimental phase the subjects were not allowed to perform any strength or endurance training of any kind that would impact the results of the study. The study was conducted according to the Declaration of Helsinki and was approved by University Committee on Human Research. No subject reported any known illness or had previously experienced EMS.

Experimental design

The total duration of the study was 4 weeks of training. Prior to the initial testing each subject was familiarized with the testing protocol and completed a full practice testing session. After this familiarization testing session, each subject was tested on three separate occasions using identical protocols: 1) before starting training, 2) after the completion of the 4-wk training period, and 3) two weeks after the end of the training period (detraining). After baseline testing, subjects were matched according to physical characteristics, maximal isometric strength, jump height, and sprint time, and then randomly assigned to one of four treatment groups that performed 4 times per week: electromyostimulation (EG, n = 10, age 19.4 ± 0.4 yr; height 1.76 ± 0.01 m; mass 72.7 ± 1.5 kg); plyometric (PG group, n = 9, age 20.8 ± 0.6 yr; height 1.79 ± 0.02 m; mass 79.7 ± 2.1 kg); combined electromyostimulation and plyometric (EPG, n = 11, age 21.4 ± 0.9 yr; height 1.79 ± 0.02 m; mass 80.2 ± 1.5 kg). A control group of ten subjects did not train and were tested before and after a 4-wk period to assess the reliability of the observations (CG, n = 10, age 20.6 ± 0.6 yr; height 1.77 ± 0.02 m; mass 71.6 ± 1.9 kg) (mean ± SD).

Training protocols

Electromyostimulation group (EG)

The EMS training of the knee extensor muscles took place four days a week for four weeks (16 sessions). Four days of training were divided by a rest day. Each session lasted ~ 34 min, made up of the following parts: 5 min of low frequency EMS warm-up (5 Hz), and 29 min where 53 isometric contractions of both knee extensor muscles were performed. Each 3-second contraction was followed by a rest period lasting 30 seconds (rest frequency: 1 Hz). The stimulator generated a biphasic symmetrical square wave signal delivered with a frequency of 120 Hz, giving a pulse width of 400 µs (Compex® Sport-P, Medicompex SA, Switzerland). A duty cycle of 10% (3 s on, 30 s off), a rise time, ramp-up of 0.75 s, and a fall time, ramp-down of 0.5 s was adopted. The current level was set individually for each subject at the maximum that could be tolerated [14,22,29], and the intensity tolerated levels were noted for each subject and session (0 – 120 mA). Three, 2-mm thick, self-adhesive electrodes were used on each thigh: one negative electrode (10 × 5 cm) was placed on the most proximal part of the quadriceps (about 10 cm below the groin) [14]; and two positive electrodes (5 × 5 cm) were placed as close as possible to the motor point of the vastus medialis and vastus lateralis muscles [18]. To standardize the knee and hip angles (Uniaxial metalic goniometer, Therapeutic Instruments®, Clifton, NJ, USA) the subjects lay down on a mat, with their feet inside a wall bar. The knee joint was fixed at an angle of 120° (180° corresponding to the full extension of the leg), the corresponding hip angle being constant throughout the 16 training sessions. This knee angle was used because it was the most effective in other studies [18,29].

Plyometric group (PG)

The plyometric training took place two days a week for four weeks (8 sessions) with one rest day in between. Each session lasted 50 min, made up of the following parts: 15 min of standard warm-up (running for 10 min, stretching exercises for 5 min, and 3 submaximal sprints), 25 min of plyometric work, and 10 min of stretching exercises. The plyometric work consisted of horizontal and drop jumps. During the initial four training sessions (wk 1 and 2) there were more horizontal jumps, with an average of 90 jumps per session (360 jumps). In the last four training sessions (wk 3 and 4) there were more drop jumps, with an average of 105 jumps per session (420 jumps). This distribution was chosen with the aim of increasing the intensity (from horizontal to vertical) and the volume (number of jumps) of the training sessions. To maintain maximal intensity, the recovery between two consecutive series of jumps was always complete (from 2 to 5 min, depending on the kind and number of jumps). During the drop jumps the subjects were asked to perform a free knee flexion position of approximately ~ 100 degrees. In doing so, we ensured an individually and preferred chosen knee flexion angle to achieve the optimal jumping height. The training was performed on an athletics track or a synthetic floor, as these are not too hard. This is a very important aspect in plyometric training due to its high harm index.

Combined electromyostimulation and plyometric group (EPG)
The 4-wk training program consisted of 16 sessions, 4 times per week: 8 EMS training sessions (2 each wk, similar to EG) and 8 plyometric training sessions (2 each wk, similar to PG). During the same week there were 2 days of EMS training and 2 days of plyometric training, with a rest day in between. In doing so, PG is thus used as control group to EPG, and the benefits due to the combined training can be differentiated. The current characteristics and the electromyostimulation protocol applied to EPG were identical to those applied to EG. Likewise, the plyometric work performed by this group was similar to the PG work.

Control group (CG)
No training was performed by the CG. This group carried out the same testing protocols as the other groups.

Testing protocols
Performance testing was initiated after a standardized 10-min warm-up that included low-intensity running, several acceleration runs, jumping at a progressively increased intensity, and stretching exercises. In all neuromuscular performance tests strong verbal encouragement was given for each subject to motivate them to perform each test action as maximally and as rapidly as possible.

20-m sprint time
The sprint running tests were performed on an indoor track. The sprint running test consisted of three maximal sprints of 20 m, with a 120-s rest period between each sprint [6]. Running time was recorded using photocell gates (AFR Systems®, AFR Technology, Spain) placed 0.4 m above the ground, with an accuracy of 0.001 s. The subjects commenced the sprint when ready from a standing start, 0.5 m behind the start line. Stance for the start was consistent for each subject. The timer was automatically activated as the subject passed the first gate at the 0 m mark. In repeated determinations of sprint running time the coefficient of variation including both biological and methodological variables was less than 1.5 %.

Jumping test
The subjects were asked to perform a maximal vertical concentric squat jump (SJ) and a maximal vertical countermovement jump (CMJ) with a preparatory movement from the extended leg position down to a freely knee flexion position (~ 100 degrees), followed by a concentric action. The jumping height was calculated from the flight time. The vertical jumps were carried out on a contact mat (SportJump-v1.0 System, DSD Inc., Spain) connected to a computer [10]. SJ and CMJ required the subjects to keep their hands on their waist throughout the jump. Knee flexion during the jumps was not standardized. Three maximal jumps were recorded, interspersed with approximately 10 s of rest, and the peak value was used for further analysis.

Maximal bilateral isometric strength
All subjects were tested for maximal voluntary bilateral isometric leg extension strength. The subject squatted in an isometric condition on a force platform (Dinascan 600 M®, Biomechanical Institute of Valencia, Spain), and was prevented from extending upwards by the shoulders being in contact with a fixed bar positioned so that the knee angle was 120 degrees. The height of the bar was maintained for each subject during the different tests. At a command a subject forcefully exerted his maximum force against the force platform by pressing his shoulders against the fixed bar. The subjects were instructed to exert their maximal force as fast as possible during a period from 2.5 – 4 s. The rest period between each maximal contraction was always 3 minutes. Three trials were completed for each test condition and the best performance trial was used for the subsequent statistical analysis. The maximal isometric voluntary contraction was expressed in relation to body weight (BW).

Thigh muscle CSA
The circumference and skinfold of both thighs were measured in the distal section, at the electrode location middle point over the vastus lateralis and the vastus medialis. In order to estimate the lean tissue area (muscle and bone) the model proposed by Knapik et al. [13] was used. Thigh cross-sectional lean area (CSA) was expressed as an averaged value of the right and left thighs. All anthropometric dimensions were taken by the same tester that had previously demonstrated test-retest reliability for $r > 0.90$ [13]. All the measurements were made three times, and the mean of the three values analyzed.

Statistical analysis
Standard statistical methods were used for the calculations of the means and standard error values. One-way analysis of variance (ANOVA) was used to determine differences among the four groups' initial maximal and explosive strength, and cross-sectional lean area. Training-related effects were assessed using a two-way ANOVA with repeated measures (groups × time). When a significant F-value was achieved, Scheffe post-hoc procedures were performed to locate the pairwise differences between the means. Selected absolute changes were analyzed via one-way ANOVA. Statistical power calculations for this study ranged from 0.80 to 0.86. The $p < 0.05$ criterion was used for establishing statistical significance.

Results

No significant changes in body mass were reflected in any group through the different assessments. Moreover, no significant

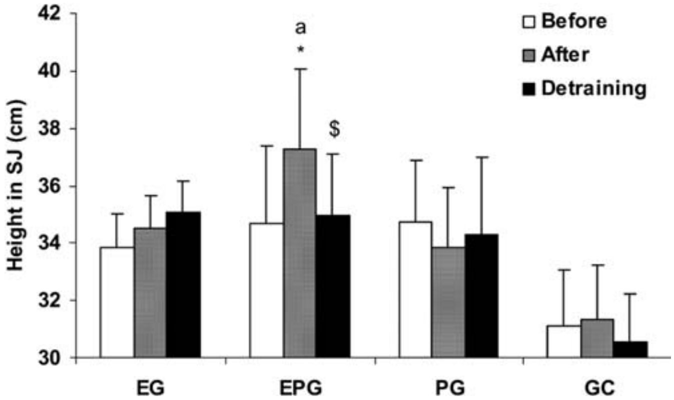

Fig. 1 Vertical jump height for squat jump (SJ) in each group before and after training, as well as after 2 wk of detraining. * and $ indicate that jump height was significantly higher than before and after training, respectively; "a" indicates significant differences in the relative changes after training with EG, PG, and CG; *, a, $ = p < 0.05. Values are means ± SE.

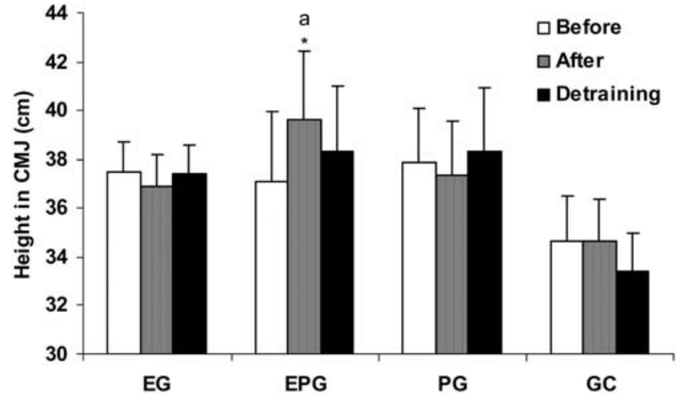

Fig. 2 Vertical jump height for countermovement jump (CMJ) in each group before and after training, as well as after 2 wk of detraining. * indicates that jump height was significantly higher than before training; "a" indicates significant differences in the relative changes with EG, PG, and CG after training; *, a = p < 0.05. Values are means ± SE.

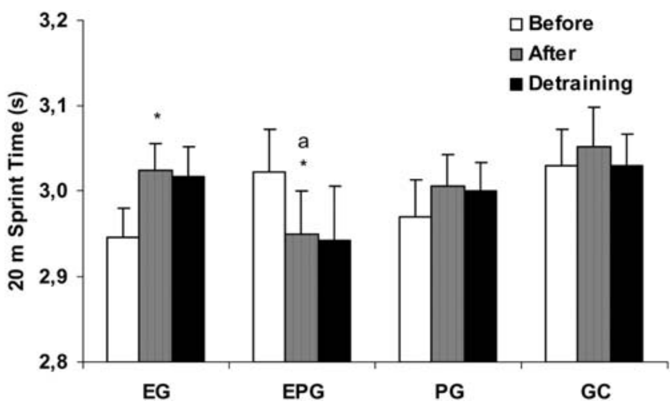

Fig. 3 20-m sprint time in each group before and after training, as well as after 2 wk of detraining. * indicates that ST was significantly different than before training; "a" indicates significant differences in the relative changes with EG, PG, and CG after training; *, a = p < 0.05. Values are means ± SE.

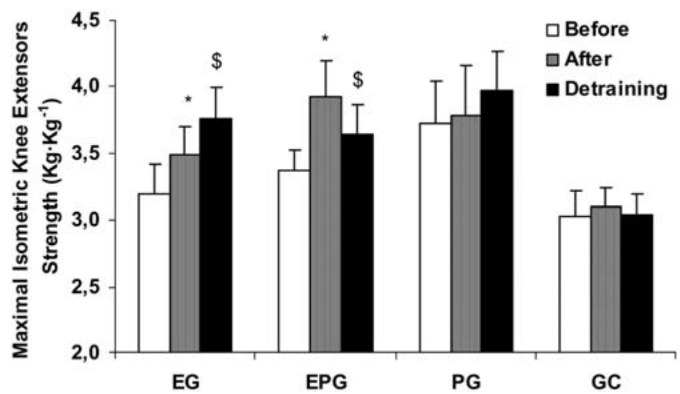

Fig. 4 Knee extensors maximal isometric voluntary contraction in each group before and after training, as well as after 2 wk of detraining. * and $ indicate that MVC was significantly higher than before and after training, respectively. *, $ = p < 0.05. Values are means ± SE.

changes were observed in PG and CG groups in any of the variables tested at any point. Significant increases in EPG ($p < 0.05$) were observed in SJ (7.5%) and CMJ (7.3%) after training (Figs. **1** and **2**, respectively). No significant changes in SJ and CMJ were observed after training or detraining for EG. No significant differences were observed in the magnitude of the changes in SJ and CMJ after detraining between EG and EPG.

A significant improvement ($p < 0.05$) in running time was observed after training (2.4%) in EG (Fig. **3**). In addition, a significant slowing ($p < 0.05$) in running time was observed after training (– 2.3%) for EPG. The improvement in running time after training in EG was greater ($p < 0.05$) than that recorded in EPG. The improvements in CMJ, SJ, and ST after training in EPG were greater ($p < 0.05$) than those recorded in EG.

A significant increase ($p < 0.05$) in MVC was observed after training (9.1%) and detraining (8.1%) in EG (Fig. **4**). A significant increase ($p < 0.05$) in MVC was also observed after training (16.3%), but not after detraining in EPG. No significant differences were observed in the magnitude of the increase between EG and EPG after training in MVC. However, the increases in MVC after detraining were greater ($p < 0.05$) in EG than those recorded in EPG. A significant increase ($p < 0.01$) in CSA was observed after training in EG (9.0%) and in EPG (7.1%), respectively (Fig. **5**). No significant differences were observed in the magnitude of the increase after training in CSA between EG and EPG.

In both EMS groups, the tolerated current intensity significant increased ($p < 0.05$) during training. During the 8 initial training sessions (from S1 to S8), no significant differences in the maximal tolerated current intensity (expressed in milliamperes) were observed among groups (Fig. **6**).

Discussion

The main findings of the study indicated that a 4-week combined electromyostimulation and plyometric training program significantly increased jumping height and sprint run in physically active men. In addition, EMS alone or EMS combined with plyometric training leads to increased maximal strength and to some

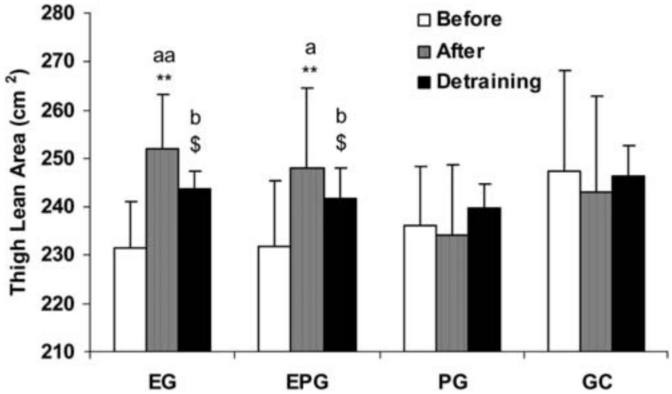

Fig. **5** Thigh lean area in each group before and after training, as well as after 2 wk of detraining. * and $ indicate that CSA was significantly higher than before and after training, respectively. "a" and "b" indicate significant differences in the relative changes with PG and CG after training and detraining, respectively. **, aa = $p < 0.01$; $,a,b = $p < 0.05$. Values are means ± SD.

hypertrophy of trained muscles. However, EMS training alone did not lead to any improvement in jumping explosive strength development, or even may interfere with sprint run. These results suggest that EMS combined with plyometric training could be used to enhance athletic performance in, for example, vertical jump and maximal acceleration.

Few studies have examined the effects of EMS-training-induced adaptations on closed kinetic explosive type of movements such as vertical jumps and maximal sprint performance. In this study EPG improved the CMJ (6.7%), SJ (7.5%), and ST (2.3%), while no significant change in jumping height, or even a decrease in ST, were observed in EG. Such findings are consistent with those of Maffiuletti et al. [18,19] and Malatesta et al. [20], who reported benefits on vertical jump after EMS training combined with basketball or volleyball training. However, these three studies [18–20] did not attempt to isolate the effects of EMS training, since they also performed jumping exercises during volleyball or basketball training sessions in addition to EMS training. In the present study, some caution must be exercised when interpreting the results because the number of training sessions was not identical between the experimental groups. However, in the present experiment, because a jumping group was controlled, one could also suggest that the training-induced changes in jumping height and sprint performance could mainly be attributed to the combination of both EMS and P, and not only to their EMS program or specific type of training program (e.g. volleyball or basketball). In line with the previously reported EMS training-induced enhancement of maximal strength, it has also been shown that EMS training alone could improve the ability to perform explosive actions during isokinetic muscle actions [4,18,21,24]. Nevertheless, no studies have shown an optimal enhancement of EMS training alone on complex explosive type of movements such as jumps or maximal running time. This indicates that EMS training alone seems to be a positive stimulus in promoting neuromuscular enhancement during "unnatural" movements such as isokinetic and isometric testing actions and isolated specific mono-articular muscle actions such as knee extensor/flexors, but does not induce optimal stimulus during more complex neuromuscular movements. It is also likely that a positive effect on height jump could be also observed if EMS would be delivered not only to the quadriceps muscle group but also to other important muscles participating in jumping or running (e.g. ankle and hip extensor and flexors), as well as leading to similar EMS times in explosive muscle actions (e.g. shorter EMS times without rise time) or inducing EMS during voluntary explosive actions. However, the effects of the EMS training with simultaneous stimulation of both quadriceps femoris and triceps surae muscles on jumping test (SJ and CMJ) are not conclusive [19,20]. Maffiuletti et al. [19] showed that 4 weeks of EMS training increased the jumping performance. On the other hand, Malatesta et al. [20] showed that jumping performances were not improved after 4 weeks of EMS training of both muscular groups. Another possible explanation could be also related to the probably unbalanced and selective electrical stimulation induced muscle gains, whereas plyometric exercise would strengthen not only the quadriceps but also the hamstrings. Finally, one may also take into consideration that the knee angle flexion used during the EMS

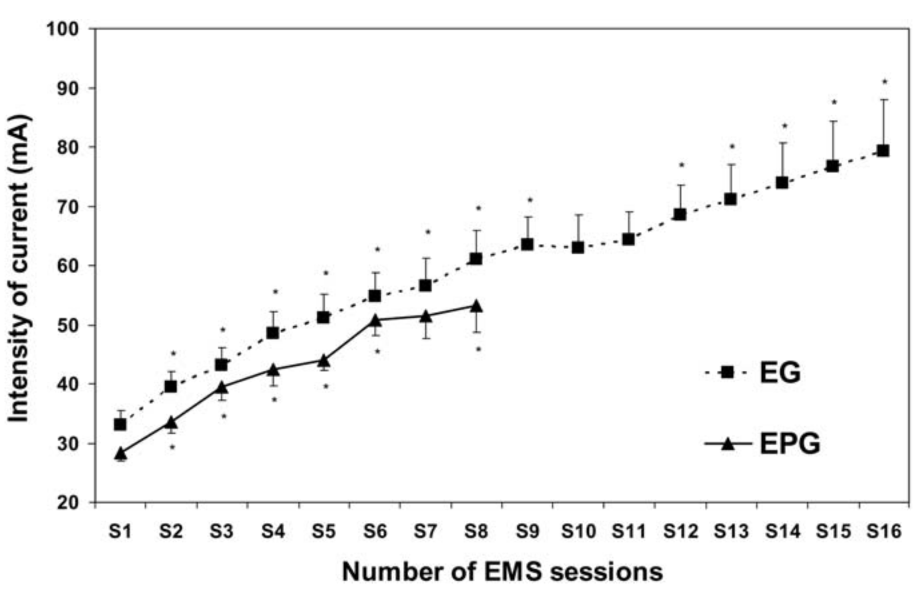

Fig. **6** Current intensity mean values tolerated by EG and EPG in each EMS training sessions (S1, S2…, S16). Differences between the indicated session and the previous session. p values: * $p < 0.05$. EG = electrostimulation group; EPG = electrostimulation and plyometric group.

training (120°) slightly differed to that individually chosen during jumping training (~100°), so that the concept of "specificity" of knee flexion angle during strength could be also considered a possible factor influencing the differences observed in jumping gains. Within the limits of our experimental results, it should be pointed out that, the maximum tolerated stimulated intensity given to the subjects did not ensure identical levels of strength evoked during the EMS contractions throughout experimental groups and training sessions. It is also likely the homogeneous and physical active groups of subjects participating in the present study may induce a small within subject variability to characterize the true intensity of the contraction at the muscle level. Therefore, the effects of multiple EMS training studies (e.g. combined with other training methods or EMS alone), as well as a true comparison between the training effects of equated volume of plyometric, EMS, and combined plyometric and EMS training on athletic performance (e.g. jumping or throwing) warrant further investigation before being applied to high-level sportsmen.

This study is the first one that has investigated the effects of EMS training on sprint performance. After 4 weeks of EMS, the ST in EPG was significantly enhanced (2.3%) in comparison to pretraining, whereas it remained unaltered or even decreased when P and EMS training were performed alone. These results contrast with the limited number of studies that have analyzed the effects of plyometric training programs on sprint performance [6,27]. These studies have observed that plyometric explosive training can be effective for improving short-distance sprint performance (2.5–2.8%) after 15–30 jumping training sessions [6,27]. In the present study the lack of significant changes in sprint performance after plyometric training alone may be related to an insufficient strength stimulus (i.e., two days a week for four weeks, 8 sessions), resulting in limited stimulation toward further increases in vertical jump and sprint performance, as well as to a lack of variation in the strength training program. However, as previously pointed out, combined EMS and plyometric training may be efficient enough to improve neuromuscular performance during complex and specific abilities such as sprints.

It is generally accepted that systematic resistance training combined with EMS can lead to considerable improvements in strength, when both the loading intensity and training duration are sufficient [2–4,18,21,22,24,28,29]. The primary mechanisms responsible for the strength performance improvements after resistance training combined with EMS has been shown to result primarily from the increased neural activation of the trained muscles [21]. Gradually, increasing muscle hypertrophy contributes to strength development during the later stages of progressive heavy resistance training [3,4,24,28,29]. The present results agree with these studies, because after 4 weeks of EMS training the maximal bilateral knee strength and the lean muscle mass of the leg muscles were significantly higher in comparison to pretraining (Figs. **4** and **5**). Initial increases in strength and muscle mass can be greater than those recorded after a similar period of resistance training alone. Ruther et al. [28] observed that increases in muscle cross-sectional area of the leg were significantly higher (10%) after 18 EMS training sessions (3–5 sets × 10 contractions × 1 s at 50 Hz and 500 µs) than those observed during a similar period of traditional voluntary resistance training program (4%). Similarly, it has been previously suggested that 12–15 EMS training sessions of the quadriceps muscle group was an effective training stimulus to enhance the maximal strength of the knee and hip extensor muscles by 22–44% [4,18, 21,22,24,29].

Nevertheless, as suggested earlier, neural adaptations may have been a more important contributing factor in the present study than that of muscle hypertrophy for strength development after EMS training [18,19,21]. Because no electromyogram data were recorded, the magnitude and time course of neural adaptations could not be evaluated. On the other hand, some caution must be exercised when interpreting the present muscle gains because the indirect method used may overestimate the lean tissue and thigh cross-sectional area.

In some instances, after highly demanding EMS training, a "rebound effect" may occur, resulting in enhanced performance when training stimulus (e.g. volume and intensity) returns to a moderate level, or even to stopping training for a short period. In the current study, training was stopped for two weeks to accomplish a "rebound effect" for all groups and avoid training volume/intensity being overreaching in nature, so that the higher volume/intensity would lead to a performance enhancement when normal training resumed over the next cycle [9,18,19]. To the best of the authors' knowledge, to what extent the effects of EMS training could be maintained or not has been only assessed after a short period of standardized volleyball or basketball training [18–20] but not after stopping training completely. These studies have observed that an additional 2 weeks of volleyball or basketball training after short-term combined EMS and plyometric training could lead to a further increase in explosive strength performance (5.5 to 17%). In contrast to previous studies [18,19], our study shows that overall explosive strength gains (e.g. height in CMJ and SJ) attained in the combined EMS and plyometric group tended to return to the pre-training values after stopping training for 2 weeks whereas, more interestingly, maximal sprint performance remained unaltered. It was also interesting to observe that in the EMS training alone, the overall maximal strength gains were significantly increased (8.1%) after stopping training for a further 2 weeks. This would suggest that initial improvements in neuromuscular function may easily be invoked after low volume combined EMS and plyometric training, but in contrast with high intensity EMS training programs, stopping training for a short period provides no further benefits.

In summary, the main findings of the study indicated that a 4-week combined electromyostimulation and plyometric training program significantly increased jumping height as well as sprint run in physically active men. In addition, EMS alone or EMS combined with plyometric training leads to increased maximal strength and to some hypertrophy of trained muscles. However, EMS training alone did not result in any improvement in jumping explosive strength development or even interfered with sprint run. The present results suggest that EMS combined with plyometric training could be used to enhance athletic performance in abilities such as vertical jump and maximal acceleration.

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