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**Research article**

# Effects of electrostimulation and plyometric training program combination on jump height in teenage athletes

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**Abstract**
The purpose of this study was to examine the effects of eight-week (2 days/week) training periods of plyometric exercises (PT) and neuromuscular electrostimulation (EMS) on jump height in young athletes. Squat jump (SJ), counter movement jump (CMJ) and drop jump (DJ) were performed to assess the effects of the training protocols 98 athletes (100 & 200m and 100m & 110m hurdles) voluntarily took part in this study, 51 males (52%) and 47 females (48%), 17.91 ± 1.42 years old, and 5.16 ± 2.56 years of training experience. The participants were randomly assigned to four different groups according to the frequency and the timing of the stimulation. Analysis of covariance was used to analyze the effects of every training program on jump height. Our findings suggest that compared to control (Plyometrics (PT) only), the combination of 150Hz EMS + PT simultaneously combined in an 8 week (2days/week) training program, we could observe significant jump height improvements in the different types of strength: explosive, explosive-elastic, and explosive-elastic-reactive. The combination of PT after ≤ 85 Hz EMS did not show any jump height significant increase in sprinters. In conclusion, an eight week training program (with just two days per week) of EMS combined with plyometric exercises has proven useful for the improvement of every kind of vertical jump ability required for sprint and hurdles disciplines in teenage athletes.

**Key words:** Jump height, squat jump, counter movement jump, drop jump, combined training.

## Introduction

Electrical muscle stimulation (EMS) consists of electrical currents application in muscles or peripheral nerves in order to obtain involuntary muscle contractions (Kots and Havilon, 1971). Several investigators have reported increased isometric muscle strength in athletes (Babault et al., 2007; Brocherie et al., 2005; Maffiuletti et al., 2002; Porcari et al., 2005), producing neuromuscular improvements (Bax et al., 2005; Colson et al., 2000; Gondin et al., 2005; Maffiuletti et al., 2002; 2009; Malatesta et al., 2003; Porcari et al., 2005). Nevertheless, EMS has some important disadvantages, such as Golgi tendon organ and myotatic reflex inhibition, which can lead to an increased injury risk (Jubeau et al, 2006; Requena et al., 2005), and some difficulties in obtaining improvements in agonist and antagonist muscle coordination (Holcomb, 2005; Paillard, 2008).

In the 1970's, Kots and Hvilon (1971) used EMS as a complementary tool for strength training in the former Soviet Union and they found strength improvements of up to 40%, providing the basis of this technique as a support in elite athletics training (Kots and Havilon, 1971). Over the last two decades, most of the EMS studies successfully aimed at lower limb power development applied to quadriceps femoris muscle (Bax et al., 2005) in athletic performance and other sport disciplines. After two months of EMS (85Hz) + PT training, an 11.2% increase was obtained for drop jump (DJ) in sprinters (Benito et al., 2010). Several studies have focused on the effect of EMS training on other sport disciplines: Volleyball, with a 6.5% and 5,4% increase for squat jump (SJ) and counter-movement jump (CMJ) respectively; Rugby, with a 10% and 6.6% improvement for SJ and DJ respectively after EMS (100Hz) training; tennis with a 10-m sprint time 3.3% shorter and a 6.4% enhancement of CMJ height (Maffiuletti et al., 2009) and soccer, with an increment of 6.7%, 2.27% and 1.71% in SJ, CMJ and ABK (Abakalov jump) respectively after 5 weeks of EMS training (Billot et al., 2010).

Vittori (1990) described two types of strength**,** active and reactive strength, and more specifically, three different types of strength manifestations: explosive, explosive-elastic, and explosive-elastic-reactive, which could be assessed by squat jump, counter-movement jump and drop jump respectively (Maulder et al., 2006). Although EMS training has been proved to be effective in improving explosive, explosive-elastic and explosive-elastic-reactive strength (Holcomb, 2006; Khlifa et al., 2010; Maffiuletti, 2008; Markovic et al, 2007; Paillard et al., 2005; Parker et al., 2003), it has been shown that the physiological adaptations produced by EMS as one single training method are slightly lower than EMS combined with sport practice (Brocherie et al., 2005; Deley et al., 2011; Holcomb, 2006), weight training (Delitto et al, 1989; Willoughby and Simpson, 1998) or plyometry (PT). EMS and PT combination have obtained improvements in vertical jump ability (Dervisevic et al., 2002; Maffiuletti et al., 2009; Malatesta et al., 2003), specific soccer skills such as ball speed (Bilot et al., 2010), sprint run (Dauty et al., 2002; Herrero et al., 2006) and anaerobic power (Herrero et al., 2010a; Herrero et al., 2010b) in both amateur (Holcomb, 2005; Jubeau et al., 2006) and professional athletes (Benito et al., 2012; Pichon et al., 1995). A recent review (Filipovic et al., 2011) reveals that EMS is effective for developing physical performance, offering a

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promising alternative to traditional strength training for enhancing the strength parameters.

To our knowledge, there is no unanimous consensus about the best specific training program for jump height enhancement according to EMS stimulation frequency (Babault et al., 2007; Benito et al., 2010; Maffiuleeti et al., 2009) and the timing of stimulation (before PT or concurrent with PT) (Gondin et al., 2005; Maffiuletti, 2002). There is some controversy about these parameters. The timing of stimulation can determine an important muscle power improvement (Benito et al., 2010) and the stimulation frequency is considered as a basic element that can determine the efficacy of a training program (Maffiuletti et al., 2000). According to the type of strength manifestation, Meaños et al. (2002) described that a frequency of stimulation of 70-90Hz and 100-150Hz could lead to improvements in explosive and explosive-elastic-reactive strength respectively. Furthermore, some authors have shown that stimulation frequency is directly related to an increase in muscle fatigue (Bickel et al., 2003; Gorgey et al., 2009). Finally, it must be considered that the improvement obtained by the combination of EMS and PT training is related to physical capacity, and thus novice athletes have a greater margin of improvement (Aceña et al., 2007), but the ideal frequency of stimulation according to the level of physical capacity has not been determined yet.

Based on these previous facts, the aim of this study was to analyze the effects of a training program based on PT and EMS according to the stimulation frequency and the timing of application. We hypothesize that high-frequency EMS action simultaneously combined with PT can lead to greater jump height improvements compared to other EMS and PT combinations.

## Methods

### Experimental approach to the problem

The study was conducted among adolescent athletes of similar experience level and it was designed to determine the right chronological order of EMS and PT application as well as the most appropriate stimulation frequency for each type of strength manifestation (SJ, CMJ, y DJ). An eight-week (2 days/week) quasi-experimental design with pre- and post-treatment measures was carried out. This is a simple randomized controlled trial with 3 treatment groups (according to the timing and the stimulation frequency) and 1 control group. SJ, CMJ and DJ height were considered as the dependent variables and the type of training was considered as the independent one.

### Sample

One hundred and thirteen medium level athletes from a total of one hundred and sixty four voluntarily decided to take part in this study. 8 athletes were excluded, 4 due to lower limb injury within the last 6 months, 3 did not received parental authorization for EMS and 1 because of being under the effects of specific medication. Finally, from the 105 participants who started the study, 7 abandoned the training program. The 98 athletes (51 males (52%) and 47 females (48%)) who completed the study were included in the final analysis. A flow diagram of the participants is presented in Figure 1. Anthropometric characteristics are: weight (58.17 ± 6.56 kg), height (1.64 ± 0.075 m), body mass index – BMI - (21.54 ± 4.57 kg·m$^{-2}$), age (17.91 ± 1.42 years old), and 5.16 ± 2.56 years of training experience (Anthropometric characteristics of the participants by gender and groups are presented in Table 1). The participants were 100 & 200m sprinters and 100m & 110m hurdles runners, enrolled in the Athletics Federation of Madrid.

Prior to participation, an informed consent or parent/guardian consent for participants under the age of 18 years was signed. None of the participants had previously engaged in EMS training. Each subject gave written informed consent to participate in the training program. The investigation protocol was approved by the Academic and Ethical Committee of the University of Jaén (Spain) according to the ethical guidelines of the Declaration of Helsinki (last modified in October 2008).

### Procedures and instruments

Prior to the study, each subject participated in two familiarization sessions with the intervention program. The participants were asked to maintain their usual food intake (lunch time from 14:00 to 15:00), 2.5 liters of daily water intake and 8 hours of sleep. The daily training was performed in the evening. After 20 minutes of warm-up, the training program was performed on Monday and Thursday for eight weeks. The rest of the days (including Monday and Thursday morning), the athletes performed their usual training program. All the participants followed the same training program.

### EMS protocol

The EMS groups participated in an 8-week training program. Organizer Psion 2 cm contact platform (Great Britain) was used to register the jump tests. A Megasonic 313-P4 Sport electrostimulation unit, Medicarim (France) was used for EMS protocol application of the training program. Three positive (5x5cm$^2$) and one negative (10x5cm$^2$) self-adhesive electrodes were placed, by three well-trained professionals over each thigh, in two different channels: channel 1 for the vastus lateralis and channel 2 for vastus medialis and rectus femoris muscles. The active electrodes were placed as close as possible to

**Table 1. Age, years of training experience (Tr. Exp.) and anthropometric characteristics of the athletes in the beginning of the study by gender and groups. Values are expressed as mean (±SD).**

| | Male (n=51) | Female (n=47) | P value | CG (n=24) | G1 (n=27) | G2 (n=23) | G3 (n=24) | P value |
|---|---|---|---|---|---|---|---|---|
| **Age (yrs)** | 18.3 (1.5) | 17.5 (1.4) | .091 | 18.0 (1.6) | 17.7 (1.3) | 18.2 (1.4) | 18.1 (1.5) | .565 |
| **Tr. Exp. (yrs)** | 5.4 (2.9) | 4.9 (2.1) | .314 | 5.2 (2.0) | 5.4 (2.6) | 5.0 (3.2) | 5.1 (2.4) | .933 |
| **Weight (kg)** | 59.9 (8.9) | 55.4 (4.9) | **.003** | 55.8 (7.2) | 61.6 (7.4) | 59.1 (7.0) | 56.2 (4.5) | **.035** |
| **Height (m)** | 1.64 (.08) | 1.63 (.06) | .599 | 1.61 (.07) | 1.68 (.06) | 1.66 (.06) | 1.63 (.05) | **.022** |
| **BMI (kg·m$^{-2}$)** | 22.1(18.8) | 18.8 (2.8) | **<.001** | 21.5 (1.5) | 21.8 (2.1) | 21.4 (1.4) | 21.2 (1.2) | .695 |

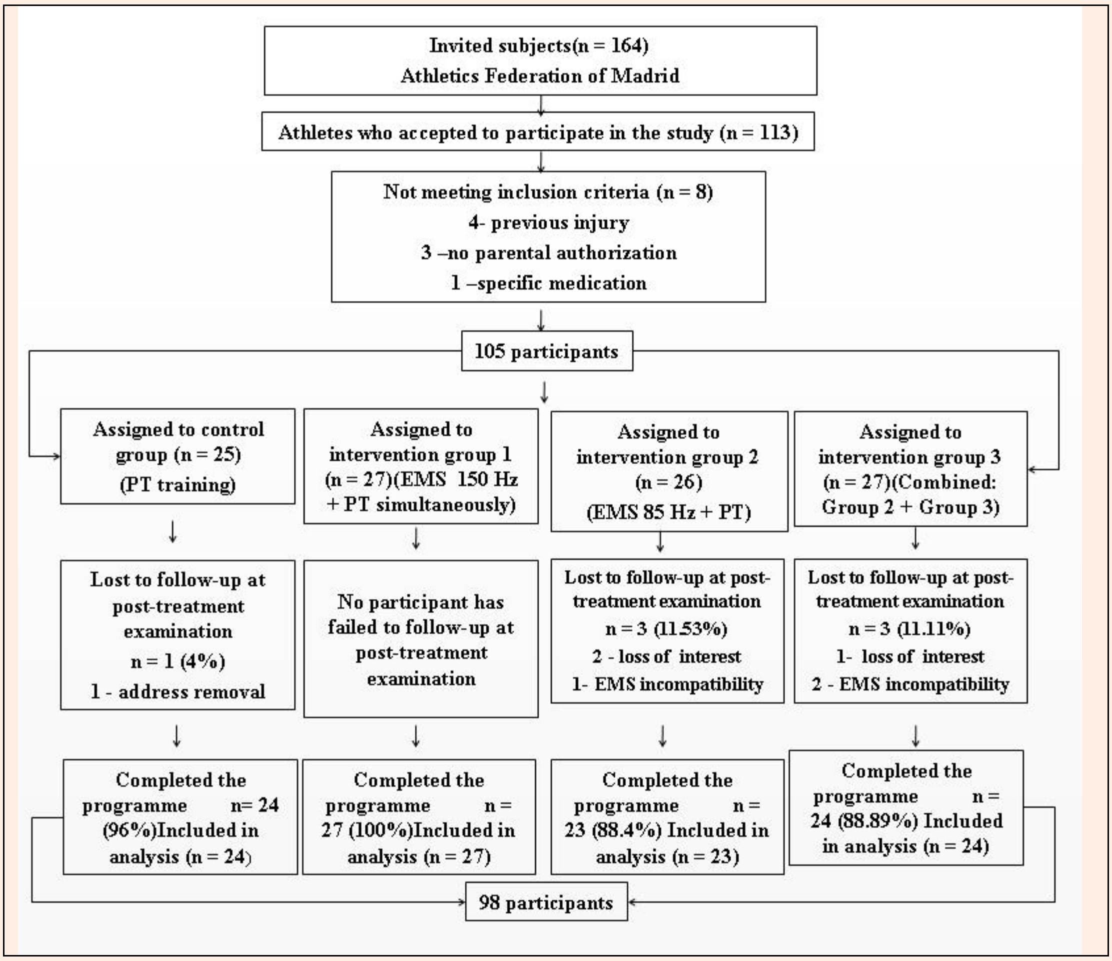


**Figure 1. Flow chart of randomized group allocation and participation throughout trial.**

the motor point of the muscles (Babault et al., 2007; Benito et al., 2010; Paillard et al., 2005) and the negative electrode was placed over the femoral triangle (Holcomb, 2005; Vanderthommen and Crielaard, 2001). The EMS parameters were: 85 and 150 Hz stimulation frequency for group 2 and 3 respectively, 350 ms pulse width and contraction-relaxation time was 3 to 12 seconds. Each EMS session lasted 12 minutes. The intensity level was set individually at the maximum tolerated (Herrero et al., 2010a) with mean levels of 25.22 ± 7.21 and 26.51 ± 5.71 mA in male and female respectively.

## Training protocols

The program consisted of 2 days/week training with PT (Figures 2a, 2b, and 2c) and EMS (Figures 2d and 2e) combination. This training program was carried out during the pre-season period (October and November). None of the athletes were participating in competitions. The athletes were divided into 4 groups and prior to the beginning of the study, they were familiarized with the training protocol for 2 days, and every exercise technique was visually shown and repeated in order to accomplish the right exercise performance. Four groups in the study received the following training conditions**:** Control group (CG, Plyometric (PT) only): The participants performed only the PT in every training session. G1: 150 Hz EMS training and PT simultaneous combination (EMS+PT). G2: PT was performed after 85 Hz EMS training (EMS/PT). G3: In this group, G1 and G2 training sessions were alternatively performed in each one of the 2 weekly training days.

## Testing protocols

Vertical jump tests have been frequently used to evaluate lower limb extensor muscle strength. PT training protocol has been established according to the plyometric method suggested by Wilt (1975). Squat jump (SJ), counter movement jump (CMJ) and drop jump (DJ) are well considered to evaluate explosive strength, explosive-elastic strength and explosive-elastic and reactive strength respectively (Cometti et al., 2001). The tests were carried out in the beginning and in the end of the study, with no prior activity in previous 48 hrs. After a 10-minute warm-up period, the participants performed three attempts of each type of jump on platform, with 2-minute rest between sets. The best of the three attempts in every jump test were registered. No EMS was applied during the jump testing. We examined the test-retest reliability of each test one week prior to the study. The participants performed two jump of each test with a 72-hour interval. The tests showed excellent intraclass correlation coefficients (R = 0.898, 95% CI = 0.885–0.948; R = 0.967,

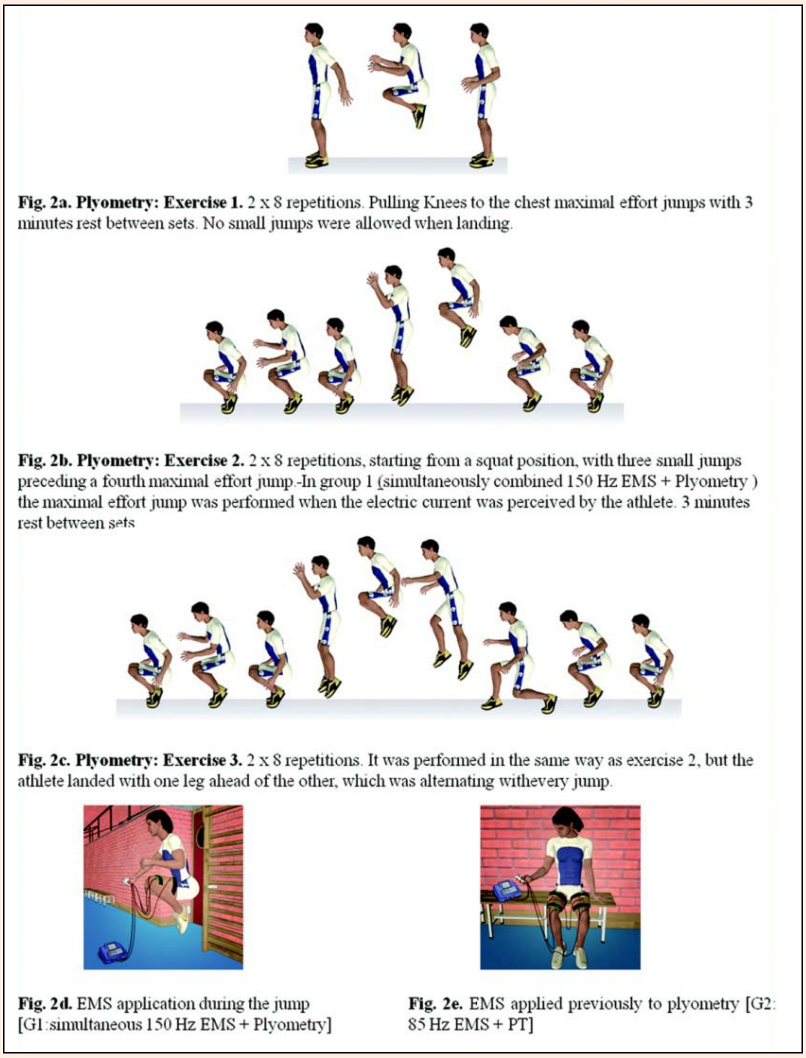

**Fig. 2a. Plyometry: Exercise 1.** 2 x 8 repetitions. Pulling Knees to the chest maximal effort jumps with 3 minutes rest between sets. No small jumps were allowed when landing.

**Fig. 2b. Plyometry: Exercise 2.** 2 x 8 repetitions, starting from a squat position, with three small jumps preceding a fourth maximal effort jump.-In group 1 (simultaneously combined 150 Hz EMS + Plyometry ) the maximal effort jump was performed when the electric current was perceived by the athlete. 3 minutes rest between sets

**Fig. 2c. Plyometry: Exercise 3.** 2 x 8 repetitions. It was performed in the same way as exercise 2, but the athlete landed with one leg ahead of the other, which was alternating withevery jump.

**Fig. 2d.** EMS application during the jump [G1:simultaneous 150 Hz EMS + Plyometry]

**Fig. 2e.** EMS applied previously to plyometry [G2: 85 Hz EMS + PT]

**Figure 2. Neuromuscular electrostimulation and plyometric exercises during the training program.**

95% CI = 0.956–0.998; and R = 0.856, 95% CI = 0.778–0.902) for SJ, CMJ, and DJ respectively.

The participants performed the following vertical jumps: the SJ started from a static semisquatting position (90º knee flexion), maintained 1 second; subjects were instructed to jump without any preliminary movement. The CMJ started from a standing position. Subjects were instructed to squat down until a 90º knee flexion angle and to extend the knee in 1 continuous movement. The DJ started from a standing position at a 40-cm height above the floor. Subjects then dropped on the contact mat, squatted down until 90º knee flexion and extended the knee in 1 continuous movement.

### Data analysis

We used a two-factor (4 group x 5 time) analysis of covariance with repeated measures to assess the training effects on the outcome variables (SJ, CMJ and DJ) after adjusting for weight and height. Analyses were performed separately for each variable. We reported the P value corresponding to the group (between-subjects), time (within-subjects) and interaction (group×time) effects. Significance was determined at $p < 0.05$. We calculated the P value for within-subjects differences by group when a significant interaction effect was present. Multiple comparisons were adjusted using Bonferroni corrections. Intraclass correlation analysis was used to assess the reliability of the tests in the beginning of the study. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, v. 16.0 for Windows; SPSS, Chicago).

## Results

All test measurements and participants characteristics, obtained at the beginning of the test, were normally distributed (kolmogorov-Smirnov) and comparables at baseline except athlete's weight and height (Table 1). No differences by sex were observed. Adherence to intervention was 93%. The program was well received by young athletes, with only 3 intolerance cases (3.1%) but no injuries or health deterioration were observed at the end of the treatment. The study protocol was carried out with no modifications or deviations.

### SJ results

The results of the SJ test (cm) and percent change scores

**Table 2. Effects of training on jump height after 8 weeks of study. ANCOVA for repeated measures 4 (group) x 5 (time) after adjustment for weight (kg) and height (cm) was used. Data are expressed as mean (±SD).**

| Variable | Group | Week 0 | Week 2 | Week 4 | Week 6 | Week 8 | Group | Time | Group x Time |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | F<br>P<br>$Eta^2$<br>1-B | F<br>P<br>$Eta^2$<br>1-B | F<br>P<br>$Eta^2$<br>1-B |
| SJ (cm) | **Control** | 25.32 | 25.57 | 26.06 | 25.37 | 27.47 | | | |
| | **(n=24)** | (5.03) | (4.67) | (4.42) | (4.77) | (4.23) | | | |
| | **G1** | 26.68 | 30.88*** | 30.73** | 29.56** | 36.30*** | (3,92)=8.33 | (4,368)=5.64 | (12,368)=8.07 |
| | **(n=27 )** | (4.41) | (6.15) | (5.66) | (3.66) | (8.42) | <.001 | <.001 | <.001 |
| | **G2** | 25.61 | 26.23 | 26.76 | 28.97* | 29.39 | .214 | .058 | .208 |
| | **(n=23 )** | (6.20) | (2.70) | (2.54) | (2.33) | (2.83) | .991 | .979 | >.999 |
| | **G3** | 27.10 | 27.70 | 29.90** | 30.85*** | 31.67** | | | |
| | **(n=24 )** | (2.24) | (2.94) | (1.63) | (1.22) | (1.80) | | | |
| CMJ (cm) | **Control** | 29.15 | 31.54 | 33.40 | 31.85 | 30.95 | | | |
| | **(n=24)** | (6.58) | (7.66) | (5.76 | (7.11 | (6.03) | | | |
| | **G1** | 31.33 | 35.14 | 34.26 | 35.42 | 37.41** | (3,92)=1.98 | (4,368)=.41 | (12,368)=6.63 |
| | **(n=27 )** | (5.83) | (6.28) | (6.70) | (6.32) | (7.03) | .122 | .801 | <.001 |
| | **G2** | 29.13 | 28.70 | 30.53 | 32.72 | 33.54 | .061 | .004 | .178 |
| | **(n=23 )** | (5.10) | (6.60) | (5.49) | (4.98) | (4.82) | .496 | .146 | >.999 |
| | **G3** | 28.43 | 31.75 | 32.03 | 34.04 | 34.22 | | | |
| | **(n=24 )** | (3.70) | (2.73) | (2.50) | (3.44) | (2.36) | | | |
| DJ (cm) | **Control** | 44.94 | 49.72 | 47.78 | 48.42 | 49.29 | | | |
| | **(n=24)** | (7.68) | (4.22) | (4.84) | (4.76) | (5.05) | | | |
| | **G1** | 48.78 | 53.63 | 52.38* | 56.88*** | 55.12** | (3,92)=4.96 | (4,368)=1.99 | (12,368)=5.60 |
| | **(n=27 )** | (7.45) | (6.80) | (6.72) | (5.95) | (5.73) | .005 | .095 | <.001 |
| | **G2** | 45.83 | 47.94 | 50.15 | 51.46 | 49.73 | .128 | .021 | .154 |
| | **(n=23 )** | (5.55) | (4.81) | (4.47) | (4.51) | (4.41) | .869 | .597 | .936 |
| | **G3** | 47.61 | 50.03 | 50.57 | 50.44 | 50.93 | | | |
| | **(n=24 )** | (4.75) | (2.15) | (2.27) | (2.86) | (3.36) | | | |

SJ = Squat jump, CMJ = Counter-movement jump, DJ = Drop jump. * p < 0.05, ** p < 0.01 and *** p < 0.001 indicate differences between experimental and control groups for the same measure.

for jump height are shown in Table 2 and Figure 3a respectively. Within and between subjects significant differences were observed on jump height ($F_{(3,92)} = 8.33$, $p < 0.001$ and $F_{(4,368)} = 5.64$, $p < 0.001$, respectively). After the multiple comparison adjustment, a significant interaction effect between group and time was observed ($F_{(12,368)} = 8.07$, $p < 0.001$). Post-hoc analysis revealed that G1 and G3 showed statistically significant increases compared to the CG in most of post-intervention measures. The results between G2 and CG were similar, except for one significant improvement of G2 in week 6 ($p < 0.05$). There was no significant time effect in each group ($p > 0.05$). No significant between and within-subjects effects for weight and jump height were observed ($p > 0.05$).

## CMJ results

The results of the CMJ test (cm) and percent change scores for jump height are shown in Table 2 and Figure 3b respectively. No between or within-groups significant differences were observed in jump height ($F_{(3,92)} = 1.98$ , $p = 0.122$; $F_{(4,368)} = 0.41$ , $p = 0.801$, respectively). A significant interaction effect between group and time was

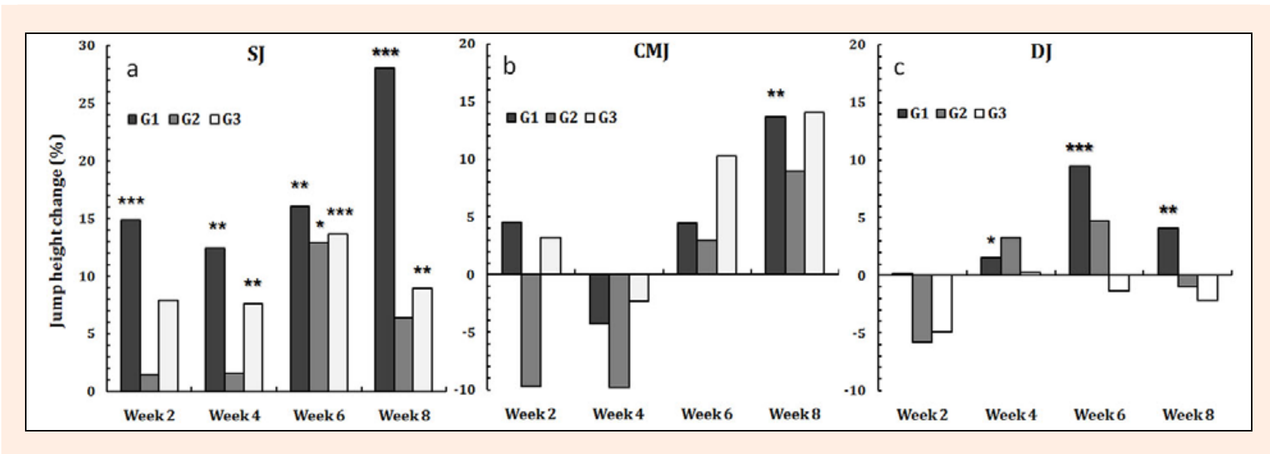


**Figure 3. Percent change scores for jump height for each test during the study. Jump height percent change was calculated as ((post - pre experimental groups) – (post – pre control group)) / pre experimental group * 100.** SJ =Squat jump, CMJ = Counter-movement jump, DJ = Drop jump. * p < 0.05, ** p < 0.01 and *** p < 0.001 indicate differences between experimental and control groups for the same measure.

observed after the multiple comparison adjustment ($F_{(12,368)}$ = 6.63, p < 0.001). Post-hoc analysis showed a significantly higher jump height in G1 (p < 0.01), compared to CG in the eighth week of training. There was no significant time effect in each group (p > 0.05). No significant between and within-subjects effects for weight and jump height were observed (p > 0.05).

### DJ results

The results of the DJ test (cm) and percent change scores for jump height are shown in Table 2 and Figure 3C respectively. We found statistically significant between-subjects differences ($F_{(3,92)}$ = 8.33, p < 0.001) in jump height but there were no significant within-subjects differences ($F_{(4.368)}$ = 1.99, p = 0.095). A significant interaction effect between group and time was observed after the multiple comparison adjustment ($F_{(12,368)}$ = 6.77, p < 0.001. Post hoc analysis revealed that, compared to the CG, G1 showed significantly higher jump height from the fourth week, and these differences became more evident in the next weeks, especially in week 6 (p < 0.001). No statistically significant differences were found in G2 and G3 compared to CG. There was no significant time effect in each group (p > 0.05). Between and within subjects tests showed a significant effect of the weight of the participants on jump height (p = 0.006 y p < 0.001 respectively), nevertheless height was not significant (p > 0.05).

## Discussion

The findings of the present study showed that a simultaneously combined EMS and PT 8-week training program (2 days/week) can lead to significant improvements in SJ, CMJ and DJ. Our results have shown that high-frequency EMS action combined with simultaneous PT application (G1) produce statistically significant improvements in sprinters compared to other combinations (EMS + PT). In fact, when PT was combined with 85 Hz EMS (G2), there was only evidence of significant improvements in SJ but any improvements in CMJ or DJ were observed. The alternate high and low stimulation frequencies (G3) showed jump height improvements in SJ and DJ but no differences were observed in CMJ.

### Squat jump height

G1 athletes (150 Hz EMS + PT), showed a significantly higher jump height (28.02%) compared to the CG at the end of the study, improving the results obtained by Maffiuletti et al. (2002) in volleyball players after 115-120 Hz EMS + PT training program (21.4% ) and by Babault et al. (2007) in rugby elite players after 100 Hz EMS + weight training (10%). G3 showed a significant jump height increase (8.93%) in week 8, but a greater and faster significant improvement was observed in G1 (week2). Finally, G2 (85 Hz EMS/PT) had only one significant increase in the 6th week (p < 0.05). These results are supported by Maffiuletti et al. (2009) and Herrero et al. (2010b), who used ≤ 120 Hz stimulation frequencies in competitive tennis players (EMS + non-specific muscle training) and physical education students (weight + PT + EMS) respectively.

These results could be influenced by the decrease in muscle elastic capacity associated with the use of EMS as a single training method (Maffiuletti et al., 2009; Paillard, 2008; Paillard et al., 2010). It has been shown that elastic strength decreases after EMS application. Nevertheless, the strength tests reflect a satisfactory progress if EMS is followed by a multi-jump training routine (Cometti, 2002). We consider that this negative influence of EMS on jump height could be compensated with a simultaneous combination of EMS+PT.

### Counter movement jump height

Based on our results, significant CMJ height improvements were only found in G1 (13.67%), greater than the data obtained by Maffiuletti et al. (2000) 8.3%, Maffiuletti et al. (2009) with 85 Hz EMS combined with non-specific muscle training in competitive tennis players (6.4%), and Billot et al. (2010) with 100 Hz EMS + non-specific soccer training amateur soccer players (6.7%). Compared to these studies (3 days/week), the jump height increase was observed with a two days/week training program, but this improvement appeared from the 8-week of training, later than other author's results.

We consider that this increase could be due to the use of a higher stimulation frequency (150 Hz) (Filipovic et al., 2011). Nevertheless, it could be also influenced by the relation between stimulation intensity and creatine kinase level of activity or by the simultaneous application of EMS+PT. This was justified by Ward and Shkuratova, (2002) who stated that the combination of voluntary exercise and EMS appeared to be more effective in increasing jump height, since the total amount of exercise is greater and it is a more complete training program, because voluntary exercise and electrical stimulation preferentially recruit different fiber types.

### Drop jump height

Finally we could only observe a statistically significant DJ height improvement in G1 compared to control group (1.56% at week 4, 9.46% at week 6 and 4.08% at week 8). Our improvement average (3.81%) was slightly lower than the results obtained by Babault et al, (2007) after 12 weeks of training (7.06%), and Benito et al, (2010), with 150 Hz EMS + PT in sprinters after 8 weeks of training (11.2%), although these results can be attributable to the longer training period (12 weeks) and the higher stimulation frequency (150Hz). Moreover, DJ results are especially relevant since simultaneous PT+EMS training would allow a positive influence for transferring the strength gains to increase transfer focused on specific types of sport movements (Filipovic et al, 2011).

Previous studies (Herrero et al., 2010a; 2010b; Herrero et al., 2006; Maffiuletti et al., 2002) showed that greater jump height improvement is observed when EMS is combined with voluntary training based on plyometric exercises, but the EMS effect combined with PT, can only be achieved with high stimulation frequency (150 Hz). Blümel (1992) described that a complete tetanus can be reached with a frequency of 200 Hz. In our study, G2 (EMS/PT) did not show any strength enhancement compared to the control group, but this result could be due to the use of a lower stimulation frequency (85 Hz) and it can be considered as a limitation to our study. Finally, when high and low frequencies were alternatively used (150 + 85 Hz) within the same training session, only SJ height increase was observed.

Although some authors have reported that EMS superimposed onto voluntary muscular contraction is more effective than exclusive voluntary muscular training (Bax et al., 2005), most of the studies have shown that higher jump height improvements were obtained when voluntary exercise and EMS are appropriately combined (Benito et al., 2010; Billot et al., 2010; Brocherie et al., 2005; Herrero et al., 2006; Maffiuleti et al., 2009; Malatesta et al., 2003), and showed a 33.3% time reduction in order to obtain the same strength (Cometti, 2002). Our findings allow us to state that, 150 Hz EMS + PT simultaneous combination can lead to different levels of jump height improvement according to the type of strength, and thus, it can be adapted to specific sport techniques that require the improvement of specific type of strength (Babault et al., 2007; Benito et al., 2010; Billot et al., 2010; Brocherie et al., 2005).

As we hypothesized high-frequency EMS action and PT simultaneously combined (EMS+PT) is the more effective combination to increase jump height. Nevertheless, it is important to consider that PT exercises must be focused on the type of strength, but because of the large number of variables studied in previous investigations (i.e., kind, volume, and intensity of the exercises), it is not easy to design an ideal training protocol according to the type of strength. Another important advantage of our training program is the fact that it was a 2 days/week protocol, whereas most of the studies have designed a 3 days/week (Babault et al., 2007; Bickel et al., 2003; Herrero et al., 2010b; Herrero et al., 2006) or 4 days/week (Dauty et al., 2002; Deley et al., 2011) training programs.

There are some limitations to our study: the first one is the use of different stimulation frequencies for each group. A second limitation is the fact that two determinant variables have been included in the same study group. This group cannot allow us to determine the single effect of each variable on every type of jump. Nevertheless, the results of the present study reveal that three important aspects must be considered in vertical jump + EMS training protocol parameters: EMS and voluntary plyometric training combination, PT exercises and EMS simultaneously combined during training performance, and finally, EMS stimulation frequency. There are some other variables that may determine the type of training, such as the gender or the period during the competitive season, which have not been considered in the present study. Further investigations should be considered to analyze these factors. According to our results, the simultaneous application of EMS + PT is associated with improvement in training efficiency and this combination could prevent the significant decrease in vertical jump height after after 3 weeks of EMS training described by Brocherie et al. (2005).

In conclusion, the results observed in this study suggest that an eight-week training program with PT and 150 Hz EMS simultaneously combined, just 2 days a week, produces significant improvement SJ, CMJ and DJ in teenage athletes. PT after EMS (≤ 85 Hz) showed SJ improvements but any jump increase was observed in CMJ or DJ. A high-frequency (≥ 150 Hz) EMS and its simultaneous application with PT can significantly contribute to the improvement of the three different types of strength manifestations (explosive, explosive-elastic and explosive-elastic-reactive strength).

The use of EMS as a complementary method in lower limb strength training can improve jump height when high frequency (150Hz) is combined or co-applied with PT training. Compared to weight training, 2 days/week of EMS and PT simultaneous combination is related to a lower joint stress and may be beneficial for athletes of this age. The timing of EMS and PT application should be considered according to the type of jump. Our results showed that 150 Hz EMS and PT simultaneously applied produced SJ, CMJ and DJ improvements, whereas only SJ height was increased when PT after 85Hz EMS and 150 Hz EMS co-applied with PT were alternatively performed. This variation of stimulation frequencies may be beneficial in preventing the muscle adaptation induced by the stimulation, providing a greater performance.

## Conclusion

In conclusion, an eight week training program (with just two days per week) of EMS combined with plyometric exercises has proven useful for the improvement of every kind of vertical jump ability required for sprint and hurdles disciplines in teenage athletes. A high-frequency (≥ 150 Hz) EMS and its simultaneous application with PT can significantly contribute to the improvement of the three different types of strength manifestations (explosive, explosive-elastic and explosive-elastic-reactive strength).

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## Key points

- The combined use of high frequency electromyostimulation and plyometric training 2 days/week in an 8 week training program produce significant improvements in jump height in teenage athletes.
- A high-frequency (≥ 150 Hz) EMS and its simultaneous application with PT can significantly contribute to the improvement of the three different types of strength manifestations (explosive, explosive-elastic and explosive-elastic-reactive strength).
- An alternate training with different stimulation frequencies [85Hz EMS/ PT combination and 150Hz EMS + PT simultaneous combination] only has significant improvement effects in SJ.
- The combination of PT after ≤ 85 Hz EMS did not show any jump height significant increase in teenage athletes.
- The timing of EMS and PT application during training must be taken into account according to the type of jump.

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