

# EFFECTS OF COMBINED ELECTROMYOSTIMULATION AND GYMNASTICS TRAINING IN PREPUBERTAL GIRLS

GAËLLE DELEY, CAROLE COMETTI, ANAÏS FATNASSI, CHRISTOS PAIZIS, AND NICOLAS BABAULT

Performance Expertise Center "Gilles Cometti", Faculty of Sports Sciences, University of Burgundy, Dijon, France

## ABSTRACT

Deley, G, Cometti, C, Fatnassi, A, Paizis, C, and Babault, N. Effects of combined electromyostimulation and gymnastics training in prepubertal girls. *J Strength Cond Res* 25(2): 520–526, 2011—This study investigated the effects of a 6-week combined electromyostimulation (EMS) and gymnastic training program on muscle strength and vertical jump performance of prepubertal gymnasts. Sixteen young women gymnasts (age  $12.4 \pm 1.2$  yrs) participated in this study, with 8 in the EMS group and the remaining 8 as controls. EMS was conducted on knee extensor muscles for 20 minutes 3 times a week during the first 3 weeks and once a week during the last 3 weeks. Gymnasts from both groups underwent similar gymnastics training 5–6 times a week. Isokinetic torque of the knee extensors was determined at different eccentric and concentric angular velocities ranging from  $-60$  to  $+240^\circ$  per second. Jumping ability was evaluated using squat jump (SJ), counter movement jump (CMJ), reactivity test, and 3 gymnastic-specific jumps. After the first 3 weeks of EMS, maximal voluntary torque was increased ( $+40.0 \pm 10.0\%$ ,  $+35.3 \pm 11.8\%$ , and  $+50.6 \pm 7.7\%$  for  $-60$ ,  $+60$ , and  $+240^\circ\text{s}^{-1}$ , respectively;  $p < 0.05$ ), as well as SJ, reactivity test and specific jump performances ( $+20.9 \pm 8.3\%$ ,  $+20.4 \pm 26.2\%$  and  $+14.9 \pm 17.2\%$  respectively;  $p < 0.05$ ). Six weeks of EMS were necessary to improve the CMJ ( $+10.1 \pm 10.0\%$ ,  $p < 0.05$ ). Improvements in jump ability were still maintained 1 month after the end of the EMS training program. To conclude, these results first demonstrate that in prepubertal gymnasts, a 6-week EMS program, combined with the daily gymnastic training, induced significant increases both in knee extensor muscle strength and non-specific and some specific jump performances.

**KEY WORDS** muscle strength, jumping ability, knee extensors, strength training, children

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Address correspondence to Gaëlle Deley, gaelle.deley@u-bourgogne.fr. 25(2)/520–526

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## INTRODUCTION

Gymnastics is a sport that requires high qualities of strength, power, and speed. However, the repetitive performance of gymnastic movements alone does not optimize the levels of strength and power required for advanced gymnasts who are already at a high level of performance (19). Thus, it has been suggested that with the incorporation of resistance training into gymnasts' regular training, it may be possible to develop better athletes physically with an integration of strength and power to complement and help to mediate gymnastic skills (22). Appropriately designed strengthening programs in prepubertal and pubertal athletes have been demonstrated to increase not only muscles strength and endurance (38) but also bone density (35) and motor skills (24). However, this training must be performed with caution, the greatest concern being the risk of an overuse soft tissue injury, particularly to the lower back (5,6,39). This is especially important because the lower back is typically the most frequently injured body part of women gymnasts (11).

Because of its local action, the electromyostimulation (EMS) technique may preserve young gymnasts from the lower back pain that could be induced by intensive strength training. This method has been used in many rehabilitation settings (4,23), but over the years, it has also proven to be an excellent alternative for strength training in several activities (2). Indeed, used alone or in association with other strengthening techniques or with specific technical work, EMS results in significant improvements both in muscle strength and anaerobic power production (jump height and sprint time) and in specific movements (9,12,25–27). Thus, high-frequency stimulations ( $>40$ – $50$  Hz), known to induce important gains in strength and velocity (18,33), might be of great interest in gymnastics. Moreover, it is noteworthy that elite women gymnasts undertake intensive training that can reach 20–25 hours per week year-round before puberty (11). Thus, EMS, which is less time consuming than voluntary program (30), could be of interest for these athletes. Lastly, as previously suggested by Maffiuletti et al. (25), adopting short EMS training programs is of great interest for 2 reasons. First, EMS imposes a particular pattern of motor unit recruitment, fast motor unit activation at relatively low force levels (17), which could be viewed as a new form of stress from a neuromuscular and metabolic point of view. Second,

beneficial effects have been observed after 4 weeks of training with only 36 minutes per week of EMS (30).

Therefore, EMS appears to be a promising strengthening method in prepubertal women gymnasts (who normally peak in performance around 16 years of age and therefore often undergo hours of strength training in addition to their 20–25 h·wk<sup>-1</sup> of gymnastics training before puberty) because it (a) preserves young gymnasts from any back pain that could occur with weight training and (b) is less time consuming. The purpose of this preliminary study was to examine the feasibility of a 6-week EMS program combined with gymnastics training on muscle strength and vertical jump ability in prepubertal women gymnasts. A control group

(training only in gymnastics) has been included in the study to verify that the observed effects do result from the EMS intervention and not from a growing effect.

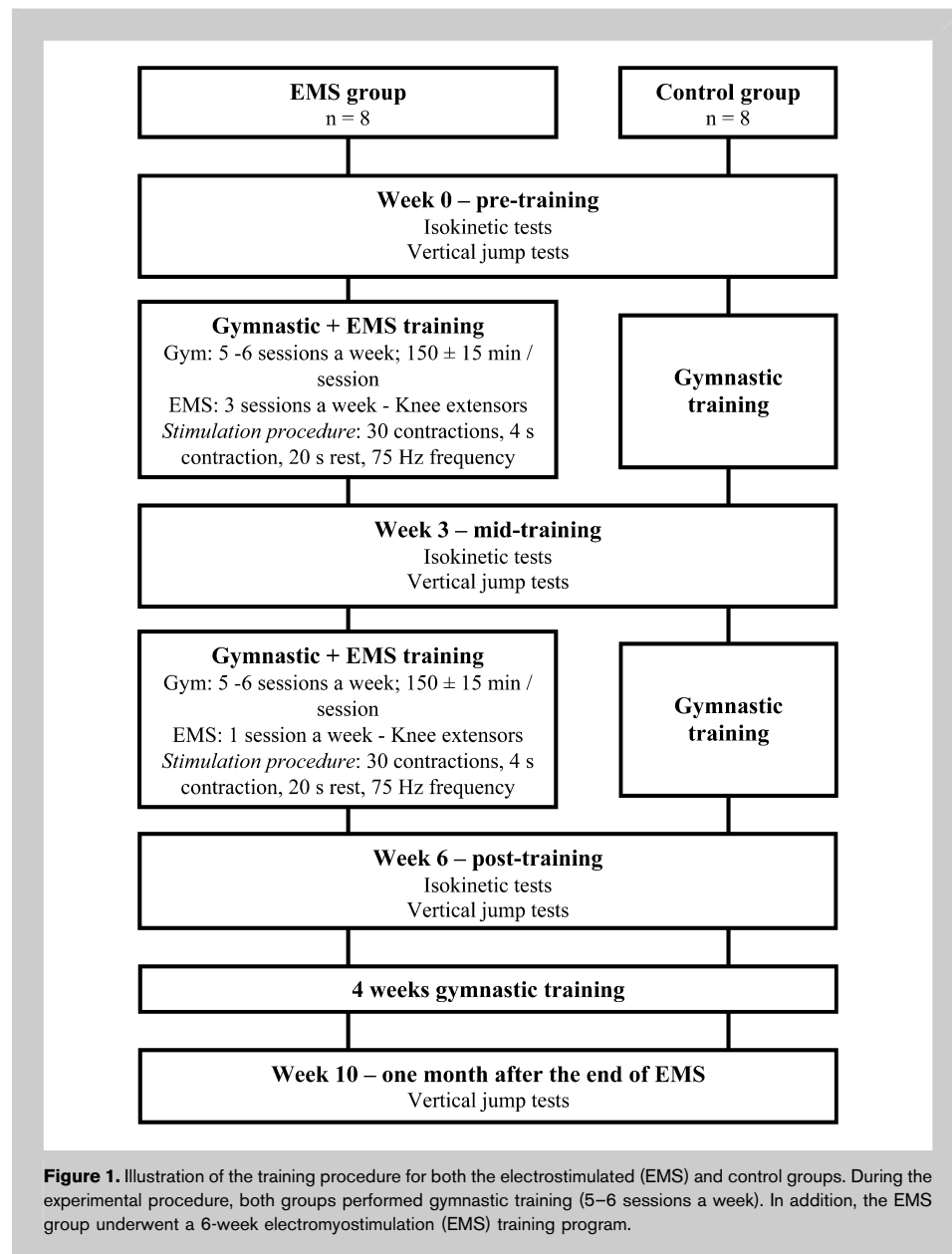
**METHODS**

**Experimental Approach to the Problem**

The present study investigated the effects of a 6-week combined training program (gymnastics plus electrostimulation) on muscle strength and vertical jump ability. All subjects (from both EMS and control groups) took part in gymnastics training, which was supervised by the same coach (5 or 6 sessions·wk<sup>-1</sup>; 150 ± 15 min·session<sup>-1</sup>). The typical training was divided into warm-up, exercises in apparatus, stretching exercises, and muscular reinforcement. Warm-up lasted approximately 30 minutes and included jogging at increasing velocities, joints mobilization, stretching exercises, and gymnast routines. Exercises and movements on the different apparatus (vault, uneven bars, balance beam, and floor) lasted approximately 100 minutes. Twenty minutes of static and active stretching exercises and muscular reinforcement (abdominal and lumbar work) ended each gymnastic training session. For the entire duration of the study, the control group was only trained in gymnastics. Muscle strength and vertical jump ability were tested for both groups before (week 0), during (week 3), and after the 6-week period (week 6). Vertical jumps were also performed 4 weeks after the end of the program (week 10) (Figure 1).

**Subjects**

Sixteen prepubertal girls (Tanner stage 1) competing gymnastics in national or regional level and free from previous knee injury volunteered to participate in the study. Subjects were randomly assigned to the electrostimulated (EMS; n = 8; age = 12.4 ± 1.2 years; height = 146.1 ± 9.8 cm; and body mass = 35.1 ± 4.9 kg) and control groups (n = 8; age = 12.4 ± 1.2 years; height = 149.3 ± 8.5 cm; and



**Figure 1.** Illustration of the training procedure for both the electrostimulated (EMS) and control groups. During the experimental procedure, both groups performed gymnastic training (5–6 sessions a week). In addition, the EMS group underwent a 6-week electromyostimulation (EMS) training program.

body mass =  $37.1 \pm 5.1$  kg). All gymnasts trained and competed regularly in gymnastics since approximately 6 years. Although they were used to undergo strength training, none of them had previously engaged in EMS programs for muscle strength training. The parents of all subjects gave written informed consent before the experiment, and the ethical approval for the project was obtained from the local committee on human research. The study was conducted in accordance with the Declaration of Helsinki.

### Procedures

**EMS Training.** Two weeks before the beginning of the training program, the EMS group underwent an EMS session for familiarization. Then, subjects were trained for 20 minutes 3 times a week during the first 3 weeks and only once a week from week 3 to week 6. Each session was separated by at least 1 day of rest, and EMS was always performed at the same time of the day (before gymnastic workouts and between 04.00 and 04.30 PM).

EMS was delivered bilaterally on knee extensor muscles using a portable battery-powered stimulator (Compex; Medicompex SA, Ecublens, Switzerland). Rectangular wave pulsed currents of 75 Hz lasting 400  $\mu$ s were used. Two self-adhesive positive electrodes (each measuring 25 cm<sup>2</sup>, 5 × 5 cm), which have the property of depolarizing the membrane, were placed on the thigh as close as possible of motor points of vastus medialis and vastus lateralis muscles near the proximal insertion of each muscle. Rectangular negative electrodes, each measuring 50 cm<sup>2</sup> (10 × 5 cm), were placed over the femoral triangle of each leg (1–3 cm below the inguinal ligament). Subjects were seated on a bench with the knee fixed in isometric position at 90° knee flexion. Pelvis was also maintained to avoid any possible leg extension or pelvic lift.

During each training session, 30 contractions were performed. Contractions were 4-second duration long followed by 20 seconds of rest. These stimulation characteristics were selected among the Compex commercially available strength programs. The intensity of stimulation was determined by the subjects at the beginning of each EMS session. It was adjusted throughout the 6-week program to always be the maximum tolerated and produce at least 60% of each individual pretest maximal voluntary contraction (MVC) score measured using a myostatic type dynamometer (Allegro, Sallanches, France). The intensity varied between 65 and 120 mA according to each gymnast's discomfort threshold. Each session was preceded by a standardized warm-up, consisting of 5 minutes submaximal EMS (5 Hz pulses lasting 200  $\mu$ s). No subject reported any serious discomfort throughout the experiment.

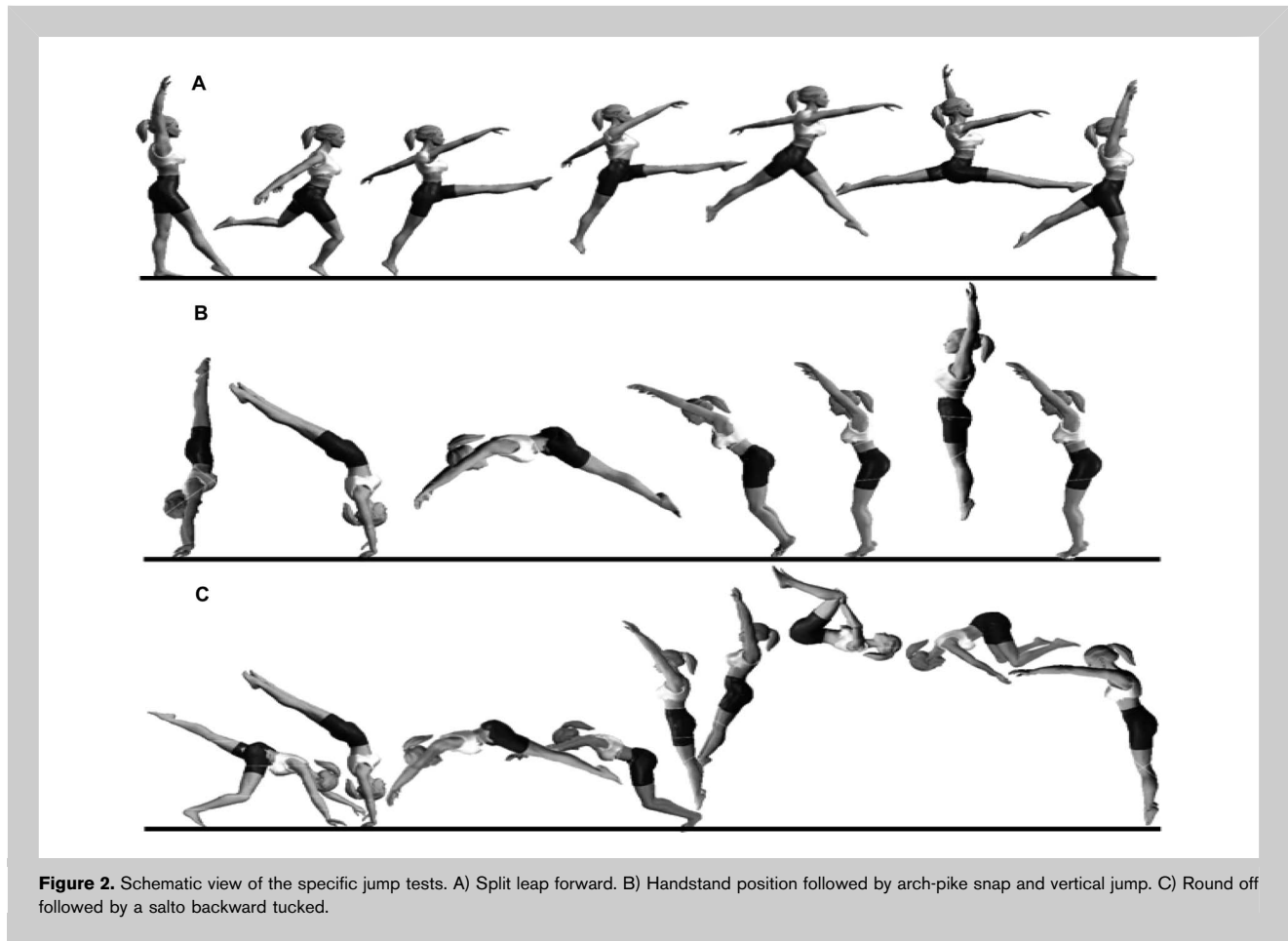
**Testing. Isokinetic tests.** Maximal voluntary torque (MVT) of the knee extensor muscles was measured at week 0, week 3, and week 6 using a Biodex isokinetic dynamometer (Biodex Corporation, Shirley, NY). Subjects were seated upright on the dynamometer chair with a 95° hip angle.

Cushions were positioned behind the back of the children to adapt the dynamometer to their size. To minimize hip and thigh motion during contractions, straps were applied across the chest, pelvis, and midthigh. The leg was fixed to the dynamometer lever arm. The axis of rotation of the dynamometer was aligned to the lateral femoral condyle, indicating the anatomical joint axis of the knee. Arms were positioned across the chest with each hand clasping the opposite shoulder. After a 10-minute standardized warm-up session, including submaximal contractions on leg extension and leg curl machines and a familiarization with the dynamometer, subjects performed quadriceps MVCs at 3 different angular velocities, 1 eccentric ( $-60^\circ \cdot s^{-1}$ ) and 2 concentric ( $+60$  and  $+240 \cdot s^{-1}$ ). Subjects performed 5 consecutive MVCs for each angular velocity. Angular velocities were randomly presented, and a 2-minute rest period was allowed between each angular velocity to avoid fatigue effects. Contractions were conducted within a 90° range of motion (from 10 to 100°; 0° corresponding to the complete knee extension). Appropriate corrections were made for gravitational effects of the leg for all torque measurements. For each trial, the 60° constant angular torque (40) was directly computed by the Biodex software and included in analyses. For each angular velocity, only the best MVT was retained for analysis. Subjects were strongly encouraged by the same investigator to perform all actions maximally, that is, throughout the whole range of motion for concentric and eccentric contractions.

**Vertical jump tests.** Jumping ability was evaluated at week 0, week 3, week 6, and week 10 using an Optojump system (Optojump; Microgate, Bolzano, Italy), measuring the flight time of the jumps. After a 10-minute warm-up composed of gymnastic movements, standard and specific vertical jump tests were performed in a random order. Three trials were carried out for each test, and the best results were retained for analysis.

Standard jump tests included the squat jump (SJ), the counter movement jump (CMJ), and the reactivity test. SJ was measured starting from a static position with a 90° knee flexion and without any preliminary movement. During this test, arms were kept on the hips to minimize their contribution. CMJ was performed starting from a standing position, then squatting down to a 90° knee angle ( $\pm 5^\circ$ ), and then extending the knees in one continuous movement. During CMJ, the arms were free to help the jump. The reactivity test consisted of 6 consecutive jumps with the assistance of arms, a slight knee flexion, and a dominant action of the ankles. The average height was calculated according to single jump flight time.

Specific jump tests included (1) split leap forward with a leg change (SL), (2) hand stand position followed by arch-pike snap and vertical jump (VJ), and (3) round-off salto backward tucked (SALTO) (Figure 2). The SL is an anterolateral jump in the pelvic axis with a leg change during the takeoff stage. After 2 steps, impulsion and landing were realized with the



same feet inside the Optojump area. Gymnasts had to perform this jump as high as possible to be able to make the leg change and a full split. The trunk and head remained upright, feet and legs tensed, and arms horizontal. The second specific jump test (VJ) is a chain of gymnastic elements: the handstand, snap down, and vertical jump. It is an important preparatory element to give speed for a sequence of acrobatic elements. The body was vertically blocked with the help of an experimenter in a handstand position. Gymnasts then realized the snap down followed by a vertical jump. The vertical jump flight time was measured for analysis. The last specific jump test (SALTO) is also a chain of 2 elements: the round off and salto backward tucked. Two steps run-up were allowed. Flight time during the backward salto was measured.

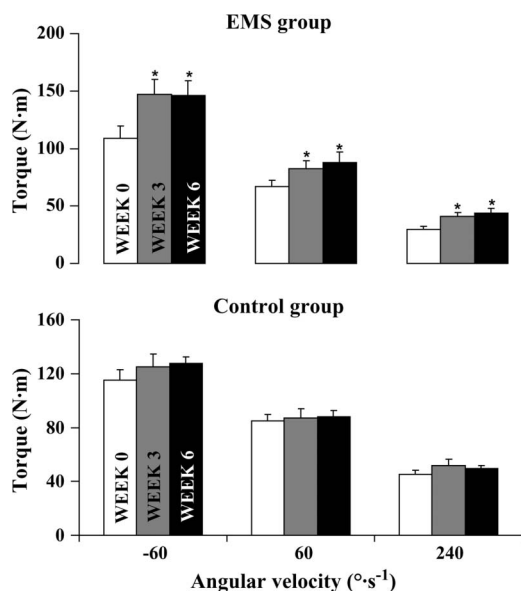
#### Statistical Analyses

Mean values ( $\pm SD$ ) were calculated for all dependent variables (knee extension torque and vertical jump height). We assessed the reliability of these data with the intraclass correlation coefficient (ICC): a 2-way random effects model with single-measure reliability in which variance over the repeated session is considered. The ICC indicates the error in

measurements as a proportion of the total variance in scores. As a general rule, we considered an ICC over 0.90 as high, between 0.80 and 0.90 as moderate, and below 0.80 as insufficient. Values were analyzed using a 2-way analysis of variance to test the effects of the intervention (time effect: week 0, week 3, week 6, and week 10) and the differences between groups (EMS or control). Time factor was analyzed as repeated measures. Subsequent Newman-Keuls post hoc tests were performed if significant main effects or interactions were obtained.  $p \leq 0.05$  was taken as the level of statistical significance for all procedures. In the present study, dependent variables were strength and vertical jumps height; and independent variables were groups (control and training groups).

#### RESULTS

The tests used in this study demonstrated good test-retest reliability, with ICCs ranging from 0.81 to 0.94. The subjects' EMS treatment compliance was 100%, and no subject reported any discomfort during and/or after the training program.



**Figure 3.** Torque-angular velocity relationship of the right knee extensors for electrostimulated (EMS) and control groups at week 0, week 3, and week 6. Values are means  $\pm$  SD. Significant differences with week 0 ( $*p < 0.05$ ).

**Isokinetic Tests**

At baseline, there was no difference between the EMS and control groups. As shown on Figure 3, MVT, measured at the 3 angular velocities, was significantly improved after only 3 weeks of training ( $+38.8 \pm 29.0\%$ ,  $+25.9 \pm 28.0\%$ , and  $+40.2$

$\pm 33.0\%$  for  $-60$ ,  $+60$ , and  $+240^\circ \cdot s^{-1}$ , respectively;  $p < 0.05$ ), and no further increase has been demonstrated between week 3 and week 6. No significant difference was observed in the control group.

**Vertical Jump Tests**

At baseline, performances in the 2 groups were similar for all jump tests. Figure 4 summarizes the results obtained for each jump test by both groups before, during, and after the 10-week period. Regarding nonspecific jumps, 3 weeks of EMS induced significant improvements for both the SJ and the reactivity test ( $p < 0.05$ ). The SJ performance was further improved at week 6 and lasted until week 10. On the other hand, 6 weeks of training were necessary to induce a significant increase of CMJ. Concerning specific jumps, the vertical jump after handstand was the only test showing a training effect ( $p < 0.05$ ). None of these parameters was changed in the control group.

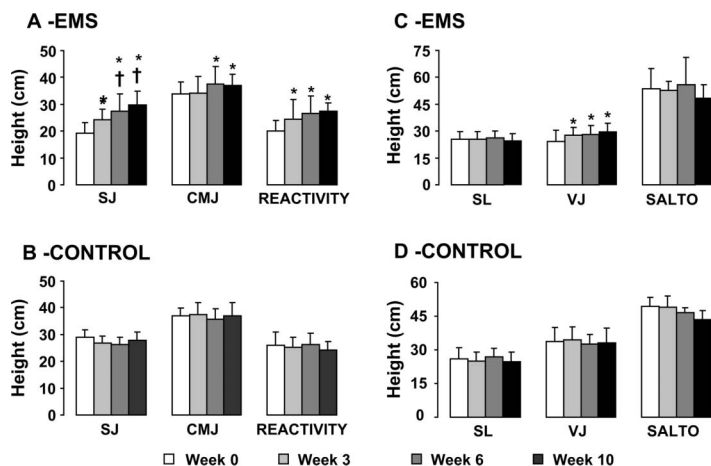
The absence of any changes in the control group confirms that the significant effects observed in this study are the results of the training program and not because of a growth effect.

**DISCUSSION**

This preliminary study has demonstrated the feasibility of a short-term progressive EMS training program combined with gymnastics training of prepubertal gymnasts. Training compliance was optimal, and EMS training program had beneficial effects on muscle strength and jump ability.

Gymnastics is a succession of explosive efforts requiring high qualities of strength, power, and speed. Therefore, in addition to the numerous hours of specific training, young gymnasts have to strength train. Several studies investigated

the effects of resistance training in children (5,6,13), and it is now universally accepted that it would induce functional and health benefits (14). Weight machines, free weights, elastic bands, medicine balls, and body mass exercises have been shown to be safe and effective in children and adolescent (1,15). However, given the already high amount of work imposed by the gymnastics training itself, we thought it could be of great interest to use EMS as a strengthening method in prepubertal gymnasts. The rationale for using EMS in young gymnasts is based primarily on 2 ideas. First, because of its local action, the EMS technique may preserve young gymnasts from the lower



**Figure 4.** Vertical jump performances in electrostimulated (EMS) and control groups; SJ: squat jump; CMJ: counter movement jump; SL: split leap; VJ: vertical jump after handstand; SALTO: round-off salto backward tucked. Values are means  $\pm$  SD. Significant differences with week 0 ( $*p < 0.05$ ). Significant differences with week 3 ( $\dagger p < 0.05$ ).

back pain that could be induced by intensive strength training (10). Second, to our knowledge, the feasibility and efficacy of this artificial training modality have never been explored in young athletes competing in individual sports requiring high levels of anaerobic power, and particularly in young gymnasts, who have a limited amount of time for conditioning because of the already high amount of time dedicated to training (20–25 h·wk<sup>-1</sup> year-round before puberty) (11).

Muscle strength was the first parameter evaluated before, during, and immediately after the training program. Our results showed a significant increase of the knee extensor muscles strength after only 3 weeks of EMS training. This result is commonly observed after short EMS programs (16,26–29,32), particularly when using high-frequency stimulations inducing tetanic contractions (18). Although our methodology did not allow to distinguish the origins of the observed gains, we assume that because of the short duration of the training program, they are mainly because of nervous adaptations (e.g., increased neural drive, spinal reflex excitability, and coactivation), rather than structural modification (e.g., hypertrophy) (16,20,28,34). Surprisingly, knee extensor's strength was not further increased between week 3 and week 6. Previous results suggested that reducing the number of sessions per week (i.e., tapering period) was beneficial for physical performance enhancements (2). However, we think that the tapering phase started too soon in the present study: decreasing the training volume after only 3 weeks may not allow any further adaptations (37). It can therefore be hypothesized that a longer initial phase is needed before starting tapering. Indeed, in a review article, Mujika and Padilla (36) suggested that by the time they start tapering, athletes should have achieved most or all of the expected physiological training adaptations.

The second parameter we were interested in was anaerobic power, tested via nonspecific and specific jumps performances. We observed significant enhancements of the nonspecific jumps height after 3 weeks for the SJ and the reactivity test, and 6 weeks for the CMJ. Moreover, further increases were observed after 6 weeks for the SJ, and this further increase lasted even after 1 month without EMS. Similar results have been observed previously, and the authors concluded that stopping EMS trainings produced persisting results (31) or delayed positive effects (26,30). Indeed, Malatesta et al. (30) obtained SJ and CMJ increases 10 days after the end of EMS training, whereas no gain was obtained immediately after the 4 weeks of training. These results may be explained by early (increased muscle activation and EMG activity) and late (increased spinal reflex amplitude and decreased coactivation) adaptations of the nervous system after an EMS training program (21). Also, the increased neural drive or preferential activation of fast muscle fibers may explain the improvement in explosive-type actions (e.g., vertical jumps) (8) by an optimization of neuromuscular properties control during complex dynamic tasks (30). On the other hand, the vertical jump after handstand was the

only specific jump improved by the EMS training program. A possible explanation of the small improvements observed for the specific jumps is their high technical skill requirements. Indeed, we found increases in the height of the nonspecific jumps and of the specific jump requiring the less technique. Similarly, several authors showed improvements in strength but not in specific tests, that is, scrumming or ice-skating (2,9). As suggested by Bobbert and Van Soest (7), strength training programs should be associated with specific exercises to improve jumping ability by an optimization of the control of neuromuscular properties. Therefore, EMS training, conducted under isometric conditions, should be accompanied with specific dynamic exercises (e.g., jumping and sprinting) for a better power improvement. Moreover, it can be hypothesized that a longer training period is necessary to allow a transfer of the gain obtained in nonspecific tests to specific ones.

Further studies evaluating the effects of a longer EMS training program and its long-term benefits in prepubertal gymnasts are needed. Also, the effectiveness of the present combined protocol in comparison to gymnastic combined with weight lifting remains to be elucidated. Finally, the physiological mechanisms responsible for strength and vertical jump increases should be carefully identified.

## PRACTICAL APPLICATIONS

Strength, power, and speed appear to be important qualities for young gymnasts who therefore undergo strength training in addition to the already high amount of gymnastics training (20–25 h·wk<sup>-1</sup> year-round before puberty) (11). On the basis of the present investigation, it appears that short-term EMS strength training could be easily integrated into the training of young gymnasts, for strength and jumping ability improvements. In the practical setting, it is suggested to combine gymnastics training with EMS, which is less time consuming than voluntary strength training (<30 min·wk<sup>-1</sup>). Moreover, in regard to its maintained and delayed effects despite the EMS volume reduction, it can be suggested that EMS strength training could be efficiently used early in the training season, and it also could be conducted during the in-season conditioning with a lower volume. EMS training volume should, therefore, be carefully periodized and sequenced with gymnastics training for optimal gains. Practically, it is suggested that after an initial 6-week period with 3 sessions a week, EMS training volume can be reduced to 1 session a week (and increased again during periods without competition).

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