Effect of combined electrostimulation and plyometric training on vertical jump height

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ABSTRACT

MAFFIULETTI, N. A., S. DUGNANI, M. FOLZ, E. DI PIERNO, and F. MAURO. Effect of combined electrostimulation and plyometric training on vertical jump height. *Med. Sci. Sports Exerc.* Vol. 34, No. 10, pp. 1638–1644, 2002. **Purpose:** This study investigated the influence of a 4-wk combined electromyostimulation (EMS) and plyometric training program on the vertical jump performance of 10 volleyball players. **Methods:** Training sessions were carried out three times weekly. Each session consisted of three main parts: EMS of the knee extensor muscles (48 contractions), EMS of the plantar flexor muscles (30 contractions), and 50 plyometric jumps. Subjects were tested before (week 0), during (week 2), and after the training program (week 4), as well as once more after 2 wk of normal volleyball training (week 6). Different vertical jumps were carried out, as well as maximal voluntary contraction (MVC) of the knee extensor and plantar flexor muscles. **Results:** At week 2, MVC significantly increased (+20% knee extensors, +13% plantar flexors) as compared to baseline ($P < 0.05$). After the 4-wk training program, different vertical jumps considered were also significantly higher compared to pretraining ($P < 0.001$), and relative gains were comprised between 8-10% (spike-counter movement jump) and 21% (squat jump). The significant increases in maximal strength and explosive strength produced by the present training program were subsequently maintained after an additional 2 wk of volleyball training. **Conclusion:** EMS combined with plyometric training has proven useful for the improvement of vertical jump ability in volleyball players. This combined training modality produced rapid increases (~2 wk) of the knee extensors and plantar flexors maximal strength. These adaptations were then followed by an improvement in general and specific jumping ability, likely to affect performance on the court. In conclusion, when EMS resistance training is proposed for vertical jump development, specific work out (e.g., plyometric) must complement EMS sessions to obtain beneficial effects. **Key Words:** SQUAT JUMP, COUNTER MOVEMENT JUMP, DROP JUMP, KNEE EXTENSORS, PLANTAR FLEXORS

Short-term programs (3–4 wk) of electromyostimulation (EMS) resistance training enable development of maximal voluntary strength during open kinetic chain contractions of the muscles of the lower limbs (9,15–17). However, athletes are generally reluctant to use EMS as a supplement to training because the stimulation is applied under isometric conditions rather than during movements for which they are training, therefore violating the principle of specificity (27). Moreover, the influence of such a training method on closed kinetic chain actions, such as vertical jump, remains elusive. Maffiuletti et al. (15) reported that a 4-wk EMS training of the knee extensor muscles significantly improved the squat jump (SJ) performance in a group of basketball players, while counter movement jump (CMJ) height significantly increased after an additional 4-wk standardized basketball training. Therefore, it seems that EMS resistance training should be followed by a short period during which the athletes may practice, in order to take full benefit of an increase in muscle strength. Such occurrence is expected, also based on the simulations of Bobbert and Van Soest (3). These authors proposed that stronger knee extensor muscles do not necessarily result in greater jumping ability, since actual performance relies crucially on the "tuning of control" to muscle properties.

Although anaerobic power production ("explosive strength") of the knee extensors and plantar flexors is an important neuromuscular performance characteristic among different athletes, very few studies have been conducted to determine the most appropriate training program for the improvement of vertical jump ability (21). Traditional weight training (7,20), "ballistic" training (21), and plyometric training (11,18) have resulted in significant vertical jump increases. According to Adams et al.(1), weight training combined with plyometrics is perhaps a greater stimulus to vertical jump performance than either weight or plyomet-

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ric training alone. However, no investigator has yet focused on EMS combined with plyometric training as part of a short-term program designed for vertical jump development. It is known that EMS training actually increases maximal strength (while explosive strength development is delayed) and plyometric training improves vertical jump performance. One could therefore hypothesize that combining these two methods would facilitate the improvement in explosive strength, which is necessary for vertical jump enhancement.

The purpose of this study was to determine the effects of a 4-wk training program combining electromyostimulation of the knee extensor and plantar flexor muscles with plyometric exercises on the vertical jump performance during the preseason preparation in volleyball. Athletes were tested: (i) in the middle of the training program (i.e., after 2 wk), to study initial alterations in maximal strength and/or jumping height; (ii) once the program completed (i.e., after 4 wk); and (iii) after 2 wk of standardized volleyball training (i.e., after 6 wk), to determine whether the effects of such training could be maintained or not.

METHODS

Twenty male volleyball players competing at the regional level in the Italian Volleyball Federation League took part in this study. All players had trained and competed regularly in volleyball for at least four yr. They agreed to participate in the study on a voluntary basis and signed an informed consent form. Approval for the project was obtained from the University Committee on Human Research. During the 6-wk experimental period, the athletes all took part in volleyball sessions, which were supervised by the same coach (3 sessions per week; ~120 min per session). Also, one friendly match was played every week. The subjects were randomly allocated to either the treatment group (age 21.8 ± 2.8 yr; height 190.7 ± 4.4 cm; mass 80.5 ± 6.7 kg) or the control group (age 22.3 ± 3.2 yr; height 180.6 ± 4.9 cm; mass 75.2 ± 8.8 kg) with 10 subjects in each group.

Combined EMS and Plyometric Training

Two weeks before the beginning of the stimulation period, the subjects from the experimental group participated in one practice session to acquaint themselves with stimulation parameters. The 4-wk training program consisted of 12 sessions lasting ~80 min each composed of three main parts: EMS of the knee extensor muscles, EMS of the plantar flexor muscles, and plyometric jumps. Each training session started with a standardized warm-up lasting 20 min (submaximal run, static stretching, knee extensions, and plantar flexions by using the training devices detailed below) followed by two MVCs of the respective muscles (see Vertical jump and MVC testing). Then, EMS of the knee extensor muscles was performed with the subjects seated on a specific strength-training apparatus (i.e., leg extension machine). The knee joint was flexed at 70° (0° corresponding to the full extension of the leg) and straps were applied across the pelvis to minimize hip and thigh motion during the contractions. For the plantar flexor muscles, subjects were asked to maintain a standing isometric position (i.e., standing calf exercise) by using a multi-power system. Hip and knee joints were positioned at 0° while ankle joint was in slight plantar flexion (~10°) to reduce pain and discomfort. For both muscular groups and for both testing and training sessions, the level of force was measured with a commercial isometric dynamometer (Ergometer Globus, Codogne, Italy), composed by a cell load secured to the frame of the machines and connected to a microprocessor, so that the direct line of force was measured.

One portable stimulator (Compex Sport-P, Medicompex SA, Ecublens, Switzerland) was used to deliver EMS and six, 2 mm-thick, self-adhesive electrodes were placed over each lower limb. The positive electrodes, measuring 25 cm^2 (5 cm × 5 cm), were placed as close as possible to the motor point of the vastus medialis, vastus lateralis, and medial and lateral gastrocnemius muscles. The two negative electrodes (10 cm × 5 cm) were placed over the femoral triangle and over the proximal aspect of the gastrocnemii, i.e., close to the proximal insertion of the respective muscle. Rectangular-wave pulsed currents (115–120 Hz) lasting 400 μs were delivered with a rise time of 0.75 s and a fall time of 0.5 s. Every 3-s steady tetanic stimulation was followed by a pause lasting 17 s, during which the subjects were stimulated at 3 Hz. In these conditions, 48 isometric EMS contractions of the knee extensors (~16 min) followed by 30 contractions of the plantar flexors (~10 min) were completed during each training session. Intensity range (0–120 mA) was monitored on-line and increased by the subject during each session to produce a force of ≥ 60% of their pretest MVC score. The maximally tolerated intensity varied between 60 and 120 mA depending on differences among subjects in pain threshold. No subject reported serious discomfort. Once the 26 min of EMS was completed, the subjects recovered passively for 10 min before performing plyometric jumps. Five sets of 10 consecutive vertical jumps with the contribution of the upper limbs were then completed, with a 3-min rest between series. Subjects performed jumps starting from a standing position, squatting down and then extending the knee in one continuous movement, so that the first jump was a counter movement jump and the nine others a type of drop jumps. To ensure maximal intensity during jumps, hurdles and benches (mean height ~40 cm) were used and subjects were verbally encouraged and supervised by the same examiner. Each training session was concluded with 10 min of static stretching of the lower limb muscles.

Vertical Jump and MVC Testing

Experimental subjects were tested before (week 0), during (week 2) and after the 4-wk training program (week 4), and once again 2 wk after the last training session (week 6). The control group was tested only before and after a 6-wk period. A standardized warm-up lasting ~15 min was carried out before each testing session and consisted of several submaximal contractions of the lower leg muscles (e.g., squat, leg extension, leg press, and jumps). Then athletes performed the following vertical jumps with their hands kept on the hips to minimize the contribution of the upper limbs: squat jump starting from a static semisquatting position (~90° of flexion) maintained for ~1 s and without any preliminary movement ($SJ_{90°}$); squat jump starting from 70° of flexion ($SJ_{70°}$); drop jump starting from a standing position on a 40-cm height, dipping, and then extending the knee in one continuous movement (DJ); counter movement jump starting from a standing position, squatting down and then extending the knee in one continuous movement (CMJ). Also, free movements of the upper limbs were allowed during counter movement jump (CMJ_A) and during simulation of a spike. An electronic timer was connected to an optical acquisition system for measuring the flight time of the different jumps (Optojump, Microgate, Bolzano, Italy). Two bars compose the system (inter-bar distance ~1.5 m): one containing the reception and control unit, the other embedding the transmission electronics. The time onset was triggered by the unloading of the subjects' feet from the ground and was stopped at the moment of the touch down. This method assumes that the position of the jumper is the same in take-off and landing. The height of jump was then calculated by using the flight time of the respective jumps (2). For the DJ and for the spike, the contact time of the feet on the ground before take off was also measured. Whatever the testing modality, subjects were asked to jump as high as they could three times, with a 2-min rest between jumps. The best performance was retained and included in subsequent statistical analysis.

After vertical jump assessment, subjects performed three maximal voluntary contractions of the knee extensor and plantar flexor muscles, by using the same experimental conditions adopted during training. Subjects were instructed to produce their maximal force without any concern for the rate of force development. Each maximal contraction was approximately 5 s in duration and 2 min of rest were provided between each contraction. During the contractions, the subjects were verbally encouraged to produce as much force as possible and the highest MVC for respective muscular group was considered.

Statistical Analysis

A repeated measures ANOVA was used to assess the effect of the training program between week 0 (i.e., baseline), week 2, week 4, and week 6 on the height of jump, contact time, and MVC of the respective muscles. When significant treatment effects occurred, Tukey *post hoc* analyses were used to test differences among means. For the control group, paired Student *t*-tests were used to compare values obtained before and after the 6-wk period. Also, independent two-tailed *t*-tests were used to analyze differences between means of variables for the experimental and control groups at baseline and at the end of the 6-wk period. The level of significance was established at $P \leq 0.05$ for all procedures. The statistical analyses were undertaken by

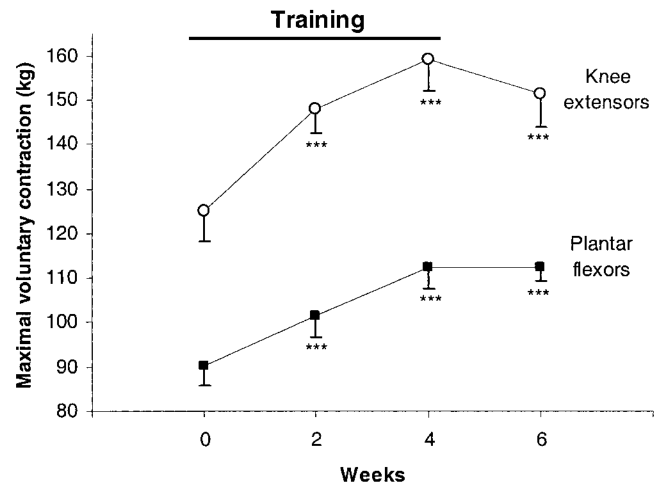

FIGURE 1—Knee extensors (open circles) and plantar flexors (filled squares) maximal voluntary contraction before (week 0), during (week 2), after the 4-wk combined EMS-plyometric training (week 4), and after an additional 2 wk of volleyball training (week 6). Values are means ± SE. * indicates that MVC value was significantly higher than baseline at $P < 0.001$ (Tukey *post hoc* test).**

using Statistica software for Microsoft Windows (StatSoft, version 5.1, Tulsa, OK).

RESULTS

After 2 wk of combined EMS and plyometric training, knee extensors and plantar flexors MVC were significantly higher with respect to baseline, respectively 20.1 ± 17.2% and 13.1 ± 8.6% (Fig. 1, $P < 0.001$). Also, DJ and $SJ_{90°}$ height significantly increased compared with pretraining (Fig. 2, $P < 0.05$), while no significant changes were observed for the other jumping modalities (Figs. 2 and 3), although there were slight increases. MVC of the two mus-

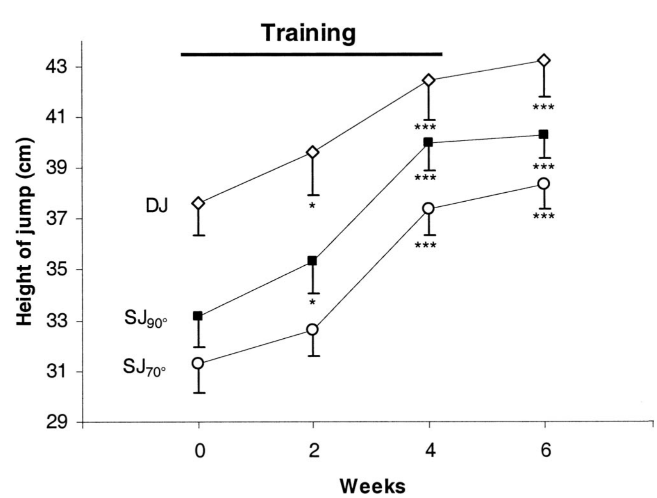

FIGURE 2—Vertical jump height for drop jump (DJ, open diamonds), squat jump starting from 90° knee flexion ($SJ_{90°}$, filled squares), and squat jump from 70° knee flexion ($SJ_{70°}$, open circles) before (week 0), during (week 2), after the 4-wk combined EMS-plyometric training (week 4), and after an additional 2 wk of volleyball training (week 6). Values are means ± SE. * and * indicate that jumping height was significantly higher than baseline at $P < 0.05$ and $P < 0.001$, respectively (Tukey *post hoc* test).**

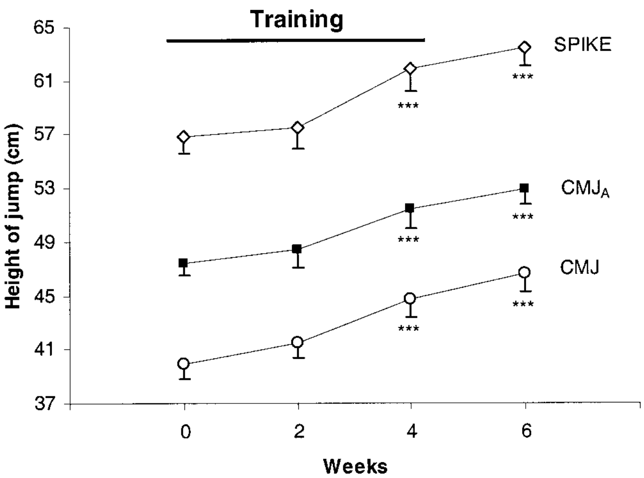

FIGURE 3—Vertical jump height for spike (open diamonds), counter movement jump with the upper limbs contribution (CMJ_A, filled squares), and counter movement jump (CMJ, open circles) before (week 0), during (week 2), after the 4-wk combined EMS-plyometric training (week 4), and after an additional 2 wk of volleyball training (week 6). Values are means ± SE. * indicates that jumping height was significantly higher than baseline at $P < 0.001$ (Tukey *post hoc* test).**

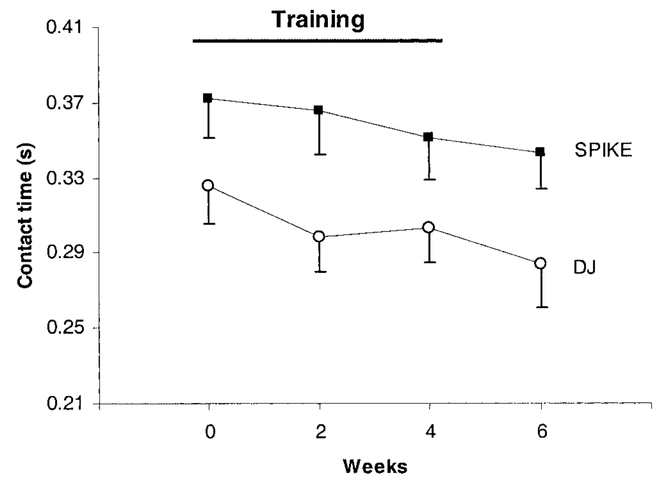

FIGURE 5—Contact time during spike (filled squares) and drop jump (DJ, open circles) before (week 0), during (week 2), after the 4-wk combined EMS-plyometric training (week 4), and after an additional 2 wk of volleyball training (week 6). Values are means ± SE.

cle groups considered further augmented at week 4 and mean gains averaged 28.5 ± 14.5% for the knee extensors and 25.4 ± 9.1% for the plantar flexors ($P < 0.001$). At the end of the 4-wk training program, vertical jump ability was significantly enhanced in all jumps ($P < 0.001$). Relative increases with respect to baseline ranged between 8.3% for the CMJ_A and 21.4% for the $SJ_{90°}$ (Fig. 4). These significant gains in vertical jump height and MVC obtained with the combined EMS-plyometric program were subsequently maintained following two weeks of volleyball training (week 6, $P < 0.001$). To better appreciate the relative increases in vertical jump performances with respect to baseline, the mean gain for each testing session is depicted in Figure 4. At week 6, gains were comprised between 11.6% for both CMJ_A and spike and 23.5% for $SJ_{70°}$. Moreover, relative increases in MVC for the knee extensor and plantar flexor muscles averaged 21.6 ± 11.9% and 26.8 ± 15.5%, respectively ($P < 0.001$). Finally, contact time during both DJ and spike slightly decreased from testing session to testing session, though not significantly so (Fig. 5).

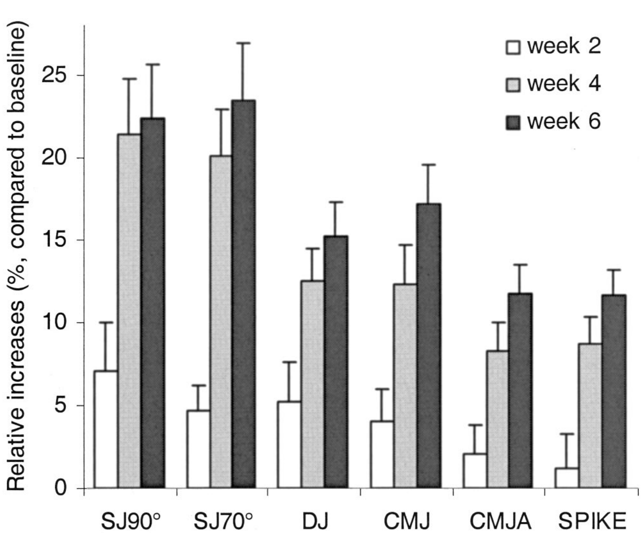

FIGURE 4—Relative increases of vertical jump height for the different modalities between baseline and week 2 (white bars), baseline and week 4 (gray bars), and baseline and week 6 (black bars). Values are means ± SE.

At baseline, the only significant difference between the experimental and the control subjects was the higher knee extensors MVC (125.1 vs 104.8 kg, $P < 0.05$) for the former group. No significant changes were observed for the control group after the 6-wk period in vertical jump and MVC performances (Table 1). At the end of the 6-wk intervention period, independent two-tailed *t*-test showed significantly higher $SJ_{70°}$, CMJ_A, spike, and MVC values in the experimental group with respect to control subjects ($P < 0.05$).

DISCUSSION

The main findings of the study indicated that a combined EMS-plyometric training program lasting 4 wk and incorporated into preseason volleyball training significantly increased the maximal voluntary strength of the knee extensor and plantar flexor muscles and the height of different ver-

TABLE 1. Jumping height and maximal voluntary contraction values before and after the 6-wk period for the control group (values are mean and SD).

	Before	After
$SJ_{90°}$ (cm)	36.6 ± 5.9	37.6 ± 6.1
$SJ_{70°}$ (cm)	34.2 ± 4.1	34.9 ± 4.2†
CMJ (cm)	42.3 ± 5.6	42.4 ± 6.0
CMJ_A (cm)	47.9 ± 5.7	48.1 ± 6.0†
DJ (cm)	39.7 ± 4.7	40.0 ± 4.5
Contact time (s)	0.32 ± 0.06	0.27 ± 0.07
Spike (cm)	53.0 ± 4.8	54.4 ± 4.8‡
Contact time (s)	0.39 ± 0.05	0.40 ± 0.06
MVC KE (kg)	104.8 ± 8.8*	106.5 ± 11.0‡
MVC PF (kg)	87.2 ± 8.7	88.2 ± 7.3‡

MVC KE, maximal voluntary contraction of the knee extensors; MVC PF, maximal voluntary contraction of the plantar flexors.
* Significantly lower than experimental group at baseline ($P < 0.05$).
† Significantly lower than experimental group after the 6-wk period ($P < 0.05$).
‡ Significantly lower than experimental group after the 6-wk period ($P < 0.001$).

tical jumps. The data also indicate that maximal strength increased more rapidly than explosive strength, and following the training program, two weeks of standardized volleyball training maintained the gains previously achieved. However, the effectiveness of the current protocol in comparison to plyometrics alone, EMS alone, or other modalities of resistance exercise has not been addressed here and therefore remains unclear. It is possible that performing only plyometrics or only EMS during the preseason volleyball training may have resulted in similar improvements as those observed after combined EMS-plyometric training. Further study is needed to compare the combined protocol used in this study to other exercises in the continued search for an optimal training regimen for vertical jump development.

In previous research, weight training (7), EMS training (15,26), or plyometric training alone (11,18) resulted in significant vertical jump height increases. Some authors have also shown the efficacy of weight training combined with plyometrics (1,10,14) for vertical jump development. For the first time, we have designed a combined EMS-plyometric training program aimed at vertical jump development during the preseason preparation of volleyball players. Another feature previously untested is that both knee extensor and plantar flexor muscles were stimulated, since their relative contribution to the total work produced during vertical jumps has been proposed to average 49% and 23%, respectively (12). Ankle (and also hip) muscle groups are often neglected, perhaps reducing the magnitude of the enhancement in a complex action, such a vertical jump.

After 2 wk of EMS training, there were significant increases of the knee extensors and plantar flexors MVC (20% and 13%), while vertical jump height improvements averaged 2% to 7%. This means that initial adaptations during the first stages of combined EMS-plyometric training are more marked for maximal voluntary strength as compared with explosive strength. The more likely explanation for such expected results is that EMS training was performed under the same experimental conditions adopted during MVC assessment (e.g., same position, same apparatus, see also Methods). Also, the duration and the type of contraction evoked by the stimulation were very similar to those of the MVC, i.e., ~5 s isometric contractions. These findings are consistent with previous reports confirming that brief periods of EMS training have immediate beneficial effect on knee extensors (9,15) and plantar flexors (16,17) maximal strength.

Increases in MVC are usually associated with changes occurring in the central nervous system (e.g., increased neural drive) and/or at the muscle level (e.g., hypertrophy). Although no EMG or cross-sectional area measurements were performed in our study, we are justified in assuming that EMS training had produced nervous rather than muscular adaptations for at least three reasons. First, it is now commonly accepted that during the first few (3 to 5) weeks of a resistance-training program, modifications at the muscle level (e.g., hypertrophy) are unlikely (19,24). Second, neural adaptations following EMS training are possible because this technique results in excitation of intramuscular branches of the nerve, and not the muscle fibers directly (13), which likely induces antidromic activation of the motor neurons. Third, one recent investigation has provided experimental evidence that the most obvious change in the function of the nervous system after four weeks of EMS training is an increase in the quantity of the neural drive from the supraspinal centers to the agonist muscle (16), likely explained by a greater number of motor units recruited. Learning (23), improved coordination between different agonist muscles (i.e., synergy), and reduced coactivation of the antagonists (5) can also be considered as possible adaptations explaining the increases in MVC observed here.

Whatever the underlying mechanism related to maximal strength gains following 2 wk of combined EMS-plyometric training, such adaptations were not associated with concomitant increases for the majority of the vertical jumps considered. Only DJ and $SJ_{90°}$ height were significantly higher at this stage (5.3% and 7.1%, respectively). Increases in the former jumping modality are not surprising, since plyometric exercises performed during the training sessions were a sort of repeated DJ, although the hands were not kept on the hips. Enhancement in $SJ_{90°}$ height is compatible with previous results indicating that initial adaptations in vertical jump performance after EMS training are more rapid for SJ as compared to CMJ (15). It must also be considered that SJ is less specific to volleyball than CMJ and thus more difficult for the athletes.

At the end of the combined EMS-plyometric training, all the jumps considered were significantly higher as compared to baseline and MVC performances further increased. These results are emphasized by the fact that in a group of volleyball players that did not complete EMS-plyometric training, neither vertical jump nor MVC performances were affected after 6 wk of classical preseason training. Newton et al. (21) have recently shown that 8 wk of ballistic resistance training (i.e., jump squats with a counter movement on a special plyometric system) significantly enhanced vertical jump in elite volleyball players, while traditional weight training (squat and leg press) had no effect. Similarly to our athletes, their subjects completed the usual preseason volleyball preparation with four to five training sessions per week. In contrast, the present training program lasted only four weeks and athletes were not elite, but subelite. This difference in the level of practice can also explain the magnitude of the gains in vertical jump performance (12–23% here vs ~6% in 21). Fry et al. (10) also reported a ~7% improvement in approach jump and reach performance by women collegiate volleyball players following a training program combining traditional weight training and plyometrics. In the current investigation, although vertical jump ability has been examined by using different jumping modalities, the more interesting finding is that spike height, i.e., the most specific volleyball jump, significantly increased by 8% at the end of the training program and by 12% after an additional 2 wk. Volleyball practice requires maximal vertical jumping that is performed repetitively during both training and competition. An increase in specific jumping ability would likely have a positive effect on performance on court.

The dissociation between maximal strength and explosive strength development found after 2 wk of combined EMS-plyometric training was not observed at the completion of the training program, since MVC and jump height gains were comparable, though not correlated. These results extend the findings of a previous study in which the effects of muscle strengthening on vertical jump height were simulated (3). These authors have shown that stronger muscles do not necessarily result in greater jumping ability, since actual performance relies crucially on the "tuning of control" to muscle properties (e.g., coordination, timing or technique). Moreover, the fact that changes in maximal strength and changes in explosive strength were not related together in our study (data not reported), confirms that the influence of maximal strength is very limited in functional tasks, such as jumping. Bobbert and Van Soest (3) therefore suggested that, in a training program aimed at improving jumping achievement, resistance-training exercises should be accompanied by exercises in which the athletes may practice with their changed neuromuscular system. Then, increases in maximal strength would necessarily be followed by explosive strength enhancement. In the same way, Adams et al. (1) have proposed that weight training combined with plyometrics is perhaps a greater stimulus to vertical jump performance than either weight or plyometric training alone. Therefore, one could conjecture that, when the aim of EMS resistance training is vertical jump development, technical work out (e.g., plyometric) as a complement to EMS sessions might facilitate the transfer between maximal strength and explosive strength, necessary for vertical jump improvement.

Many factors would have contributed to the increased performance in the various vertical jumps after 4 wk of combined EMS-plyometric training. For example, it is possible that the ability of the neuromuscular system to produce concentric force rapidly may have been enhanced, although not assessed with the present methodology. Also, high alactic but also lactic (6) power production following training would necessarily have had a positive effect on vertical jump height, also considered that anaerobic ATP cost is higher for electrically induced exercise than for voluntary exercise (22) and that an acute EMS session induces significant accumulation of lactate (9). In this experiment, reductions in contact time during drop jump and spike (Fig. 5) seem to indicate an improvement in stretch shorten contraction performance, likely determined by the utilization of potential energy stored in the series elastic component during muscular lengthening. Fiber type can also be considered as a possible factor accounting for vertical jump increases, since EMS may preferentially activate the largest motor units (8) and the associated fast twitch fibers contribute considerably to the performance in SJ and CMJ (4). However, the influence of these "peripheral" factors (i.e., at the muscle level) is extremely complex in functional tasks such as jumping. It is the opinion of the authors that the adaptability of the central nervous system played a key role in the vertical jump increases observed here. The execution of these rapid actions relies heavily on preprogrammed muscle stimulation patterns (3,25). Optimization of such templates within the central nervous system (at supraspinal level) probably took place in our athletes following maximal strength increases and allowed adjustment of control to neuromuscular properties during explosive efforts, thus improving vertical jump height. According to Van Zandwijk et al. (25), afferent feedback can only play a limited role in the control of maximal vertical jumps, because of the short execution time. The fact that EMS training affected supraspinal centers in one previous study, while no changes were observed at the spinal cord level (16) supports our assumptions.

The overall gains produced by the present 4-wk EMS-plyometric training were maintained after an additional 2 wk of standardized volleyball training. Knee extensors MVC slightly decreased but, more interestingly, jumping heights further increased whatever the jump considered, though not significantly so. Similar results have previously been reported for basketball players one month after the end of an EMS training program (15). As a practical application, combined EMS-plyometric training incorporated into the preseason preparation could be useful to volleyball players in at least two ways. First, such a training modality enhances vertical jump performance without interfering with volleyball training. Second, players' abilities can subsequently be maintained at a high level throughout the season by means of volleyball training only.

In conclusion, the combined EMS-plyometric protocol utilized in this investigation resulted in significant improvements in maximal strength and explosive strength during the preseason volleyball training. Future research is warranted to determine the influence of different combinations of EMS and resistance-training protocols on MVC and vertical jump ability. Also, the effectiveness of the present combined protocol in comparison to plyometrics alone or other modalities of resistance training remains to be elucidated. Finally, the physiological mechanisms responsible for strength and vertical jump increases should be carefully identified.

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