Journal of Strength and Conditioning Research, 2003, 17(3), 573–579

Effects of Electromyostimulation Training and Volleyball Practice on Jumping Ability

DAVIDE MALATESTA,[1] FABIO CATTANEO,[2] SERGIO DUGNANI,[2] AND NICOLA A. MAFFIULETTI[3]

[1]*Laboratoire de Physiologies des Interactions, Hôpital A. de Villeneuve, Montpellier, France;* [2]*Facoltà di Scienze Motorie, Università degli Studi di Milano, Italy;* [3]*Faculté des Sciences du Sport de Dijon, Université de Bourgogne, Dijon, France.*

ABSTRACT

The aim of this study was to investigate the influence of a 4-week electromyostimulation (EMS) training program on the vertical jump performance of 12 volleyball players. EMS sessions were incorporated into volleyball sessions 3 times weekly. EMS consisted of 20–22 concomitant stimulations of the knee extensor and plantar flexor muscles and lasted ~12 minutes. No significant changes were observed after EMS training for squat jump (SJ) and counter movement jump (CMJ) performance, while the mean height and the mean power maintained during 15 seconds of consecutive CMJs significantly increased by ~4% ($p < 0.05$). Ten days after the end of EMS training, the jumping height significantly ($p < 0.05$) increased compared with baseline also for single jumps (SJ +6.5%, CMJ +5.4%). When the aim of EMS resistance training is to enhance vertical jump ability, sport-specific workouts following EMS would enable the central nervous system to optimize the control to neuromuscular properties.

Key Words: squat jump, counter movement jump, consecutive jumps, mechanical power

Reference Data: Malatesta, D., F. Cattaneo, S. Dugnani, and N.A. Maffiuletti. Effects of electromyostimulation training and volleyball practice on jumping ability. *J. Strength Cond. Res. 17(3):573–579. 2003.*

Introduction

During the last few years, increasing attention has been drawn to electromyostimulation (EMS) as a modality for strength training in healthy subjects and highly trained athletes (9, 11, 17, 19–21, 27; see also 10 and 14). Indeed, growing evidence indicates that high-frequency EMS training actually increases maximal voluntary contraction of the lower limb muscles during open kinetic chain efforts (19–21). For example, short-term (4-week) EMS protocols have been reported to increase maximal isometric and dynamic strength of the plantar flexor (20, 21) and knee extensor muscles (19), likely explained by changes in the function of the nervous system (e.g., increased activation; see 20). Whether or not such EMS training-induced neural adaptations can positively affect closed kinetic chain actions, such as the vertical jump, still remains unanswered.

Only one study has examined whether EMS training had an effect on vertical jump performance in team sports (19). These authors reported that EMS training of the knee extensor muscles significantly improved maximal voluntary strength and squat jump performance in a group of basketball players; however, counter movement jump height significantly increased only after an additional month of standardized basketball training. Therefore, it seems that EMS resistance training should be followed by a short period of sport-specific (e.g., basketball workout and competition; 19) in order to take full benefit of the increased muscle strength. These findings seem to support the claims of Bobbert and Van Soest (3), who report that stronger knee extensor muscles do not necessarily result in greater jumping ability because actual sport performance relies more specifically on the ''tuning of control'' of muscle properties. Considering the fact that the execution of maximal vertical jumping relies heavily on preprogrammed muscle stimulation patterns (26), delayed optimization of such templates within the central nervous system can result in delayed development of vertical jump ability after EMS resistance training.

Although anaerobic power production of the lower limb muscles is an important neuromuscular performance characteristic among volleyball players, very few studies have been conducted to determine the most appropriate training program for the improvement of vertical jump ability during the preseason training period (see 23). ''Ballistic'' training (23), plyometric training (15), and weight training combined with plyometrics (13) have resulted in significant vertical jump increases in both men and women volleyball athletes. However, because preseason preparation aims at increasing several physical as well as technical skills, training for vertical jump ability must be optimized in terms of time. In this context, EMS can be considered more attractive than voluntary training because previous EMS programs lasted only 4 weeks and the duration of each session did not exceed 18 minutes (19–21). Voluntary training protocols and sessions are usually more time consuming (see, e.g., 15 and 23). Therefore, the aim of this study was to determine whether or not a 4-week electromyostimulation training program, incorporated into the preseason volleyball training, could affect vertical jump performance in a group of 12 players. Based on the findings of Maffiuletti et al. (19), we hypothesized that the effects of EMS training on jumping ability would be enhanced following a short period of standard volleyball practice because this additional training period would allow for optimization of the preprogrammed muscle stimulation patterns.

Methods

Experimental Approach to the Problem

Twelve men volleyball players competing at the regional level in the Italian Volleyball Federation League took part in this study (age 17.2 ± 0.3 years; height 181.8 ± 6.3 cm; mass 73.0 ± 4.2 kg). All players had trained and competed regularly in volleyball for at least 4 years. They agreed to participate in the study on a voluntary basis and signed an informed-consent form. The study had the approval of the local ethical committee. The 40-day experimental period started 2 weeks after the beginning of the preparatory training season and finished immediately before the competitive season. During these 40 days, the athletes all took part in volleyball sessions (3 sessions per week, ~120 minutes per session), which were supervised by the same coach, i.e., one of the authors. Also, one friendly match was played every week. The typical volleyball session was divided into warm-up, main, and recovery periods. The warm-up lasted ~20 minutes and included jogging at increasing velocities, submaximal contractions of the upper-body muscles (e.g., crunches, pull-ups, push-ups), submaximal jumps and both upper- and lower-body stretches. The main part of the session included on-court skills training (attacking and defensive fundamentals, technical workouts, special situations) and actual game play. The work/rest ratio was close to 1:1. None of the subjects completed specific plyometric or weight training for the lower limb muscles during the 40-day experimental period. The EMS treatment occurred over the first 30 days while the remaining 10 days included only standard volleyball sessions. During this short 10-day period, the volleyball workouts were almost the same as in the first 30 days (without any EMS training), albeit more time was devoted to actual game play. Because we have previously reported that vertical jump performance did not show any significant change after 6 weeks of preseason volleyball training, similar to the current study, i.e., same coach, same volleyball training, and same skill level of the players (unpublished observations), a control group was not included.

Table 1. EMS parameters.

Waveform	Biphasic symmetric rectangular pulses
Pulse width, duration	400 μs
Pulse rate, frequency	105–120 Hz
Duty cycle	4.25 s on, 29–34 s off (11–13%)
Rise time, ramp up	0.75 s
Fall time, ramp down	0.5 s
Amplitude, intensity	Subject's maximum tolerated (60–100 mA)
Treatment time	~12 min
Total number of contractions	20–22

EMS Training

One week before the beginning of the stimulation period, the subjects participated in one practice session to acquaint themselves with stimulation parameters. Individual EMS sessions lasted ~12 minutes, and each of the three sessions per week (22) was incorporated into the volleyball training sessions. Due to scheduling difficulties, subjects randomly completed the 3 weekly EMS sessions either at the beginning, in the middle, or at the end of the individual volleyball training sessions. EMS was consistently supervised by the same investigator, and particular attention was also paid to the athletes during the volleyball workouts subsequent to EMS training.

According to Lake (17), the important parameters of EMS include waveform and current types, pulse or burst duration, pulse or burst frequency, duty cycle, amplitude ramp modulation, and stimulus current amplitude. Table 1 shows the characteristics of the electrical stimulation selected for the present training protocol. Concerning waveform, the simplest stimulus protocol is to apply a train of rectangular pulses (10). It must also be considered that conventional stimulus waveforms such as those adopted here and elsewhere (i.e., biphasic rectangular pulses) are known to alter the recruitment order of motor units (12) and may actually be advantageous for strength training (10). Moreover, because chronaxie for the motor axons being electrically stimulated is between 200 and 400 microseconds, then rectangular pulses of similar duration should be considered (3, 25). Pulse duration was 400 microseconds in our protocol, also based on the fact that longer durations (300–400 microseconds) produce a more powerful contraction (3). The most efficient frequency of repetitive stimulation (or frequency modulation) appears to range from 50 to 120 Hz (14); therefore, we selected the highest frequencies in this range. According to Hainaut and Duchateau (14), the stimulus regimens should comprise a duty cycle (i.e., an active-rest cycle), which will minimize the effects of muscle fatigue. Although little is known about the optimal rest period and/or modality during EMS, a duty cycle of 11–13% was adopted here and rest consisted of low-frequency (1 Hz) and low-intensity stimulations. Because optimal ramp, electrode placement, and current intensity are also critical for best results, the recommendations of several recent reviews on EMS have been considered (10, 14, 17, 25; see below). Previous EMS studies completed in our laboratory have also confirmed the validity of the electrical stimulation parameters adopted here for the enhancement of knee extensor (19) and plantar flexor (20, 21) strength.

In the current investigation, both quadriceps femoris and triceps surae muscles were stimulated simultaneously and bilaterally by using two portable stimulators (Compex-2, Medicompex SA, Ecublens, Switzerland). During the stimulation, subjects were asked to maintain a half-squat isometric position by using a Technogym multipower system (Technogym, Gambettola, Italy) with 250 kg placed on the barbell. Hip, knee, and ankle joints were positioned at ~90° of flexion. Considering the fact that electrical stimulation superimposed on voluntary contraction does not strengthen muscle any more than EMS treatment alone (8, 18), 6 subjects exerted maximal force against this isometric load while the other 6 subjects were asked to maintain the correct body position under the barbell during stimulation. In both cases, the load was not raised and EMS induced isometric contraction of the knee extensor and plantar flexor muscles. Because such training modality violates the principle of specificity for volleyball players, stimulations were delivered while subjects maintained a closed kinetic chain position. Indeed, it has recently been shown that squat training allows improvement of the vertical jump height, while open kinetic chain training has no significant effect (2). Six, 2-mm-thick, self-adhesive electrodes were placed over each lower limb. The positive electrodes, measuring 25 cm^2 (5 cm × 5 cm), which had membrane depolarizing properties, were placed as close as possible to the motor point of the vastus medialis, vastus lateralis, medial, and lateral gastrocnemius muscles (17). 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. Intensity range (0–100 mA) was monitored on-line and increased by the subject during each session. The maximally tolerated intensity varied between 60 and 100 mA depending on differences among subjects in pain threshold. No subject reported serious discomfort from this current.

Vertical Jump Testing

Subjects were tested at baseline (pre), after the 4-week EMS training (post), and once again 10 days after the last EMS session (post10). A standardized warm-up lasting ~15 minutes was carried out before each testing session and consisted of several submaximal contractions of the lower limb muscles (e.g., squat, leg extension, leg press, jumps). Then athletes performed the following vertical jumps on a contact mat: squat jump (SJ), counter movement jump (CMJ), and 15 seconds of consecutive CMJs. An electronic timer was connected to the mat for measuring the flight time of the different jumps (Ergojump—Bosco system). The time onset was triggered by the unloading of the subject's feet from the mat and was stopped at the moment of touch down. This method assumes that the position of the jumper on the mat is the same in take-off and landing. During all tests, the hands were kept on the hips to minimize the contribution of the upper limbs. The position of the upper body was also standardized so that a minimum of flexion and extension of the trunk occurred. The SJ was measured starting from a static semisquatting position maintained for ~1 second and without any preliminary movement. The CMJ was performed starting from a standing position, squatting down and then extending the knee in one continuous movement. In each case, the height of jump was calculated according to Asmussen and Bonde-Petersen (1). Also, CMJs were consecutively repeated during 15 seconds without any recovery between jumps. For this modality, the mean jumping height and the mean mechanical power per kilogram of body weight were computed by using the total number of jumps, total flight time, and total contact time over the 15-second period (5). Whatever the testing modality, subjects were asked to jump as high as they could three times (15, 23), with a 2-minute rest between SJ and CMJ and 5 minutes between 15-second bouts of consecutive CMJs. The best performance was retained and included in the analysis.

Statistical Analyses

Ordinary statistical methods were used to calculate means, standard deviations (*SD*s), and standard errors (*SE*s). A repeated measures ANOVA was used to assess the effect of EMS training between pre, post, and post10 on the SJ and CMJ height of jump and on the mean height and mean power maintained during 15-second bouts of CMJs. When significant treatment effects occurred, Tukey post hoc analyses were used to test differences among means. The level of significance was established at $p \leq 0.05$ for all procedures.

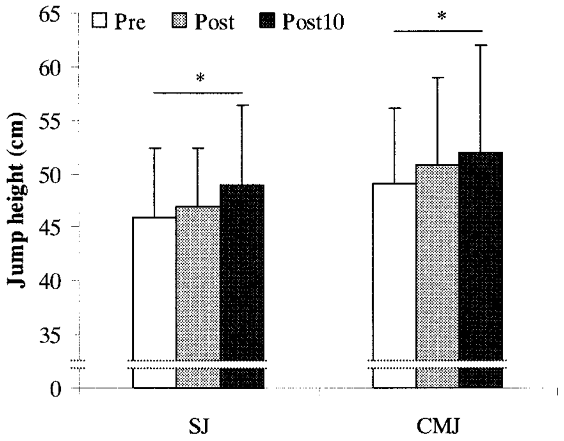

Figure 1. Vertical jump height for squat jump (SJ) and counter movement jump (CMJ) before and after the 4-week EMS training program and 10 days after the last EMS session (post10). Values are means and error bars correspond to *SD*s. * Indicates that jumping height at post10 was significantly higher than pretraining at $p < 0.05$.

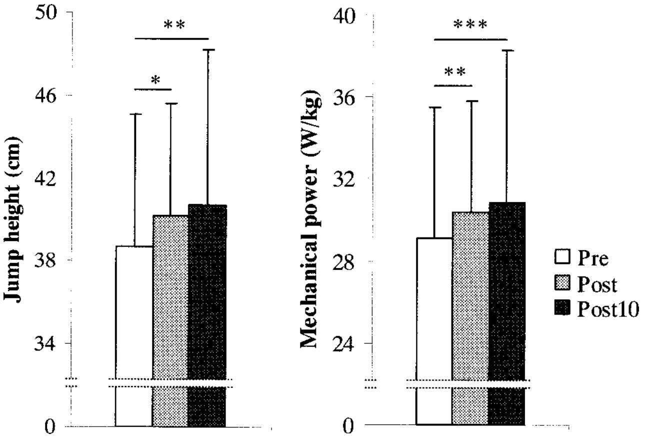

Figure 2. Mean vertical jump height and mean mechanical power maintained during the 15 seconds of consecutive CMJs before and after the 4-week EMS training program and 10 days after the last EMS session (post10). Values are means and error bars correspond to *SD*s. *, **, and *** Indicate that posttraining and post10 (10 days after the last EMS session) values were significantly higher than pretraining values at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

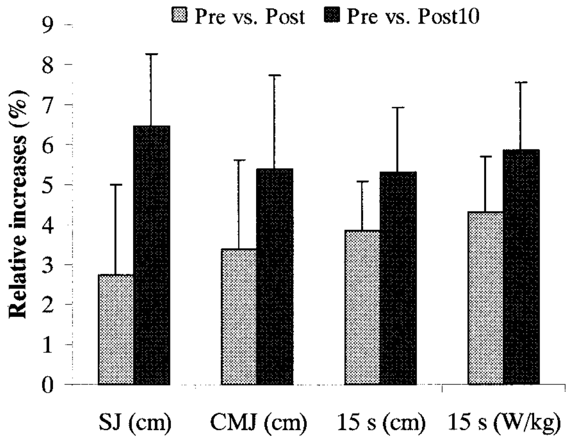

Figure 3. Relative increases of vertical jump height and mean mechanical power for single and continuous jumps between pretraining and posttraining values and between pretraining and post10 values. Values are means and error bars correspond to *SE*s.

Results

No significant changes in SJ and CMJ performances were observed after 4 weeks of EMS training (Figure 1, pre to post), while the mean height and the mean mechanical power maintained during 15-second bouts of consecutive CMJs significantly increased, by 3.8 ± 4.3% ($p < 0.05$; Figures 2 and 3) and by 4.3 ± 4.7% posttraining ($p < 0.01$), respectively. However, 10 days after the last EMS training session (post10), the maximal height of each jump was significantly higher when compared with baseline (Figures 1 and 2). SJ height significantly increased, by 6.5 ± 6.3% (Figure 3; $p < 0.05$), CMJ height by 5.4 ± 8.1% ($p < 0.05$), and 15-second height by 5.3 ± 5.5% ($p < 0.01$). Moreover, the mean mechanical power per kilogram of body mass maintained during the consecutive CMJs was significantly higher compared with baseline (+5.9 ± 5.5%; $p < 0.001$).

Discussion

The main findings of the study indicated that a 4-week electromyostimulation training program, incorporated into the preseason volleyball training, significantly increased the mean jumping height and mechanical power during 15 seconds of consecutive CMJs but did not modify performance in single jumps (SJ and CMJ). The data also indicated that, following the EMS program, 10 days of standardized volleyball training significantly enhanced CMJ and SJ performance by ~5–6%. According to previous investigations (19, 27), EMS may be a useful way for developing anaerobic power during closed kinetic chain actions, such as vertical jump.

Volleyball practice requires a short but intense effort, i.e., maximal vertical jumping, that is performed repetitively during both training and competition. Chamari et al. (7) have observed that, during a volleyball match, each time a player passes from one of the three forward positions, he jumps about 6 times, with a mean recovery of ~20 seconds between jumps. However, although anaerobic power production during vertical jump is an important neuromuscular performance characteristic among volleyball players, the effectiveness of different resistance training programs for the improvement of such ability has not been assessed systematically. Newton et al. (23) have recently shown that 8 weeks of ballistic resistance training (i.e., jump squats with a counter movement on a special plyometric system) significantly increased vertical jump in elite volleyball players (+6%), while traditional weight training (squat and leg press) had no effect. In addition, all subjects completed the usual preseason volleyball preparation with 4–5 training sessions per week. Similar results were observed in the current study, with the exceptions that the training program was shorter (4 weeks), subjects were younger, and significant gains in single jumps were only obtained after a short period (10 days) of volleyball training following the EMS training.

After 4 weeks of EMS, the mean height and the mean power maintained during 15 seconds of consecutive CMJs were significantly higher as compared with pretraining. This represents the only significant change observed immediately after EMS training. We are aware that such jumping modality is not specific to volleyball, but that this type of training does affect the lactic anaerobic metabolism. Indeed, it has recently been shown that, in elite volleyball players, a significant venous blood lactate concentration occurred after a single vertical jump and after 6 consecutive jumps (7). Thus, both lactic and alactic anaerobic energy systems are of importance in volleyball and they both must be stressed with specific training programs. Based on the present findings, it can be proposed that 4 weeks of isometric EMS training represents a valid method for stimulating the lactic anaerobic metabolism. This is not surprising because Eriksson et al. (11) have reported a significantly increased lactate formation in the vastus lateralis muscle after an acute EMS session.

The lack of change in single-jump heights following the completion of the EMS training program is not a novel finding because Maffiuletti et al. (19) have observed that CMJ height was unchanged in elite basketball players after a similar 4-week program. In keeping with our findings, a supplementary 4-week period of basketball training alone did result in significant jumping gains. These authors concluded that performance in complex movements using the stretch shortening cycle, such as CMJ, requires a period of specific training before the beneficial effects of EMS can be observed. Based on the present results, similar conclusions can also be extended to movements without a stretch shortening cycle, i.e., squat jump, because an additional 10 days of normal volleyball practice following the EMS program allowed CMJ and SJ height to increase. Performance in single vertical jumps (i.e., anaerobic power or ‘‘explosive’’ strength) is influenced by several muscular and/or neural factors. Changes at these levels during the 10 days of volleyball training could explain the ‘‘delayed’’ enhancement of jumping ability. For example, it is possible that the ability of the neuromuscular system to produce maximal strength and/or concentric force rapidly may have been enhanced, although not assessed with the present methodology. High alactic but also lactic (see above; 7) power production following training could have had a positive effect on vertical jump height because the anaerobic ATP cost is higher for electrically induced exercise than for voluntary exercise (24). The comparable increases observed here for SJ and CMJ seem to indicate an improvement in the stretch shortening contraction performance, likely due to 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 because EMS preferentially activates the largest motor units (10) and the associated fast-twitch fibers contribute considerably to the SJ and CMJ performance (4). However, the influence of these ‘‘peripheral’’ factors (i.e., at the muscle level) is extremely complex in functional tasks such as jumping, and it seems unlikely that such modifications occurred during the 10 days of normal volleyball workouts and not during the initial 30-day training period. It can therefore be conjectured that the adaptability of the central nervous system played a key role in the vertical jump increases observed here. Indeed, the execution of these rapid actions relies heavily on preprogrammed muscle stimulation patterns (6, 26) because afferent feedback can only play a limited role due to short execution time. Optimization of such templates within the central nervous system probably took place in our athletes during the specific volleyball training and allowed for the adjustment of control to the neuromuscular properties during the vertical jumps. The fact that similar EMS training affected mainly supraspinal mechanisms in one previous study (20) reinforces the above assumptions. It can therefore be concluded that, when the aim of EMS resistance training is to enhance vertical jump ability, sport-specific workouts following the EMS training would then enable the central nervous system to optimize the control to neuromuscular properties.

In the current study, both knee extensor and plantar flexor muscles were concomitantly stimulated because their relative contribution to the total work produced during vertical jumps has been proposed to average 49 and 23%, respectively (16). To the best of our knowledge, the effects of plantar flexor EMS training on vertical jump performance have never been studied previously. As a matter of fact, in typical EMS training protocols, only the quadriceps femoris muscle is stimulated when the subject is seated in a leg extension machine (18, 19), and the ankle and hip muscle groups are often neglected, perhaps reducing the magnitude of the potential improvement in a complex action such as a vertical jump.

In the present methodology, the specificity between the type of effort adopted during training and testing has also been respected, i.e., closed kinetic chain action. In fact, Augustsson et al. (2) have recently shown that squat exercise training improved vertical jump performance by 10%, while no changes were observed after open kinetic chain (i.e., leg press) training. However, our EMS training was basically a form of isometric strength training, and it is well known that there are some practical limitations to subjecting athletes to this type of training. It can therefore be concluded that, when conceiving an EMS training program for the enhancement of vertical jump ability, the choice of the trained muscles (knee extensors and plantar flexors) and their type of action during training (closed kinetic chain) have a major impact on the result, even when the type of muscular contraction performed during training (i.e., isometric EMS) is not specific to the testing contraction.

Practical Applications

Specific training programs such as ballistic training or EMS training should be recommended to volleyball players in order to develop their vertical jumping ability. As a practical recommendation, it is suggested that EMS training could be used to enhance vertical jump performance without interfering with sport-specific volleyball training and would be best used early in the volleyball training season. EMS training provides an advantage over ballistic training for improving vertical jump ability when time availability for physical conditioning is limited. Indeed, ~36 minutes of EMS per week during 4 weeks followed by 10 days of volleyball training resulted in significant increases in vertical jumping ability for our subjects. Ballistic training protocols usually require more than 36 minutes per week (see, e.g., 15 and 23); however, it must be kept in mind that EMS training does not have an immediate positive effect, contrary to ballistic resistance training (23). A period of specific training lasting 10 days (present study) to one month (19) should follow an EMS training program before single-jump ability increases. Future research is warranted to replicate these findings and determine the influence of concomitant EMS and ballistic (e.g., plyometric) training on maximal voluntary strength and vertical jump ability in team sports like volleyball and basketball. Also, the mechanisms responsible for ''delayed'' vertical jump increases following EMS and the possible involvement of neural adaptations remain to be carefully identified. Further study will also focus on (i) the effectiveness of EMS used statically versus dynamically, (ii) the optimal EMS training protocol, and (iii) the effects of EMS vs. voluntary training on vertical jump ability.

References

1. ASMUSSEN, E., AND F. BONDE-PETERSEN. Storage of elastic energy in skeletal muscles in man. *Acta Physiol. Scand.* 91:385–392. 1974.
2. AUGUSTSSON, J., A. ESKO, R. THOMEE, AND U. SVANTESSON. Weight training of the thigh muscles using closed vs. open kinetic chain exercises: S comparison of performance enhancement. *J. Orthop. Sports Phys. Ther.* 27:3–8. 1998.
3. BOBBERT, M.F., AND A.J. VAN SOEST. Effects of muscle strengthening on vertical jump height: A simulation study. *Med. Sci. Sports Exerc.* 26:1012–1020. 1994.
4. BOSCO, C., AND P.V. KOMI. Mechanical characteristics and fiber composition of human leg extensor muscles. *Eur. J. Appl. Physiol.* 41:275–284. 1979.
5. BOSCO, C., P. LUTHANEN, AND P.V. KOMI. A simple method for measurement of mechanical power in jumping. *Eur. J. Appl. Physiol.* 50:273–282. 1983.
6. BOWMAN, B.R., AND L.L. BAKER. Effects of waveform parameters on comfort during transcutaneous neuromuscular electrical stimulation. *Ann. Biomed. Eng.* 13:59–74. 1985.
7. CHAMARI, K., S. AHMAIDI, J.Y. BLUM, O. HUE, A. TEMFEMO, C. HERTOGH, B. MERCIER, C. PREFAUT, AND J. MERCIER. Venous blood lactate increase after vertical jumping in volleyball athletes. *Eur. J. Appl. Physiol.* 85:191–194. 2001.
8. CURRIER, D.P., AND R. MANN. Muscular strength development by electrical stimulation in healthy individuals. *Phys. Ther.* 63: 915–921. 1983.
9. DELITTO, A., M. BROWN, M.J. STRUBE, S.J. ROSE, AND R.C. LEHMAN. Electrical stimulation of quadriceps femoris in an elite weight lifter: A single subject experiment. *Int. J. Sports Med.* 10: 187–191. 1989.
10. ENOKA, R.M. *Neuromechanics of Human Movement.* Champaign, IL: Human Kinetics, 2002.
11. ERIKSSON, E., T. HAGGMARK, K.H. KIESSLING, AND J. KARLSSON. Effect of electrical stimulation on human skeletal muscle. *Int. J. Sports Med.* 2:18–22. 1981.
12. FEIEREISEN, P., J. DUCHATEAU, AND K. HAINAUT. Motor unit recruitment order during voluntary and electrically induced contractions in the tibialis anterior. *Exp. Brain Res.* 114:117–123. 1997.
13. FRY, A.C., W.J. KRAEMER, C.A. WESEMAN, B.P. CONROY, S.E. GORDON, J.R. HOFFMANN, AND C.M. MARESH. The effect of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *J. Appl. Sport Sci. Res.* 5:174–181. 1991.
14. HAINAUT, K., AND J. DUCHATEAU. Neuromuscular electrical stimulation and voluntary exercise. *Sports Med.* 14:100–113. 1992.
15. HEWETT, T.E., A.L. STROUPE, T.A. NANACE, AND F.R. NOYES. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. *Am. J. Sports Med.* 24:765–773. 1996.
16. HUBLEY, C.L., AND R.P. WELLS. A work energy approach to determine individual joint contributions to vertical jump performance. *Eur. J. Appl. Physiol.* 50:247–254. 1983.
17. LAKE, D.A. Neuromuscular electrical stimulation. An overview and its application in the treatment of sports injuries. *Sports Med.* 13:320–336. 1992.
18. LIEBER, R.L. Skeletal muscle adaptability. III: Muscle properties following chronic electrical stimulation. *Dev. Med. Child Neurol.* 28:662–670. 1986.
19. MAFFIULETTI, N.A., G. COMETTI, I.G. AMIRIDIS, A. MARTIN, M. POUSSON, AND J.C. CHATARD. The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. *Int. J. Sports Med.* 21:437–443. 2000.
20. MAFFIULETTI, N.A., M. PENSINI, AND A. MARTIN. Activation of human plantar flexor muscles increases after electromyostimulation training. *J. Appl. Physiol.* 92:1383–1392. 2002.
21. MARTIN, L., G. COMETTI, M. POUSSON, AND B. MORLON. Effect of electrical stimulation on the contractile characteristics of the triceps surae muscle. *Eur. J. Appl. Physiol.* 67:457–461. 1993.

22. Morrissey, M.C. Electromyostimulation from a clinical perspective. A review. *Sports Med.* 6:29–41. 1988.
23. Newton, R.U., W.J. Kraemer, and K. Häkkinen. Effects of ballistic training on preseason preparation of elite volleyball players. *Med. Sci. Sports Exerc.* 31:323–330. 1999.
24. Ratkevicius, A., M. Mizuno, E. Povilonis, and B. Quistorff. Energy metabolism of the gastrocnemius and soleus muscles during isometric voluntary and electrically induced contractions in man. *J. Physiol.* 507:593–602. 1998.
25. Vanderthommen, M., and J.M. Crielaard. Electromyostimulation en médecine du sport. *Rev. Med. Liege* 56:391–395. 2001.
26. Van Zandwijk, J.P., M.F. Bobbert, M. Munnrke, and P. Pas. Control of maximal and submaximal vertical jumps. *Med. Sci. Sports Exerc.* 32:477–485. 2000.
27. Wolf, S.L., G.B. Ariel, D. Saar, M.A. Penny, and P. Railey. The effect of muscle stimulation during resistive training on performance parameters. *Am. J. Sports Med.* 14:18–23. 1986.

Acknowledgments

The authors are especially indebted to Dr. Michael G. Bemben from the Department of Health and Sport Sciences (University of Oklahoma at Norman) for critical reading of the paper.

Address correspondence to Dr. Nicola A. Maffiuletti, Nicola.Maffiuletti@u-bourgogne.fr.