Effects of Two Types of Neuromuscular Electrical Stimulation Training on Vertical Jump Performance

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Abstract

Paillard, T, Noe, F, Bernard, N, Dupui, P, and Hazard, C. Effects of Two Types of Neuromuscular Electrical Stimulation Training on Vertical Jump Performance. *J Strength Cond Res* 22: 1273–1278, 2008—This study examined the effects of different types of neuromuscular electrical stimulation (NMES) programs on vertical jump performance. Twenty seven healthy trained male students in sports-sciences were recruited and randomized into three groups. The control group (C group, n = 8) did not perform NMES training. Two other groups underwent 3 training sessions a week over 5 weeks on the quadriceps femoris muscle [F group (n = 9): stimulation with an 80 Hz current for 15 min for improving muscle strength; E group (n = 10): stimulation with a 25 Hz current for 60 min for improving muscle endurance]. The height of the vertical jump was measured before NMES training (test 1), one week (test 2) and five weeks (test 3) after the end of the programs. The results showed that the height of the vertical jump significantly increased in both the F and E groups between tests 1 and 2 (5 cm and 3 cm respectively). Results of test 3 showed that both groups preserved their gains. A NMES training program destined to improve muscle endurance does not interfere on vertical jump performance. It can even durably enhance it in the same way as a NMES training program destined to improve muscle strength. Thus, to improve muscle endurance without deteriorating muscle power, sportsmen can use electrical stimulation.

Key Words electrical stimulation, squat jump, stimulation parameters

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Introduction

Many studies have shown that the voluntary maximal strength of the lower limbs can increase after only three to five weeks (from two to five sessions a week) of training by neuromuscular electrical stimulation (NMES) in healthy subjects (2,5,17,21,24,25,26,29) and sportsmen (19,20). Moreover, many parameters can modulate this strength improvement, such as the number of NMES sessions (24), the different waveforms of the current (2,16,30), the stimulation frequency (14,15) or the current intensity (26). Nevertheless, after NMES training enhancements can be observed in muscle strength while decreasing performance in a complex movement like a vertical jump (6). Performing a vertical jump requires the activation of synergic muscles which cannot be simultaneously stimulated by NMES (22). Conversely to NMES, training with programs using voluntary movements improve inter-muscular coordination (22). Thus, the improvement of performance in a complex movement requires the enhancement of both the muscle strength and the motor control (3). Another major difference between NMES and complex sports movements is linked to the muscle action, since NMES is applied under isometric conditions whereas sports movements are mainly dynamic. Hence, NMES does not fit the specificity required for the completion of sports movements. Therefore, to be in line with this specificity, many authors have proposed training programs where NMES is combined with voluntary sport training (18,19, 20,31). While evaluating the effects of these programs, these authors showed that the combination of NMES and sport training enhanced the vertical jump performance. However, no studies have been conducted to compare the effects of different types of NMES training programs on vertical jump when NMES was combined with sport training.

It is widely accepted that reaching the maximal effects on muscle contractility is achieved with a high frequency (50 to 120 Hz) during a short duration of stimulation and a long rest period (11,15). Hence, the question arises as to whether different frequencies (high and low) and different durations of stimulation and different rest periods can differently influence vertical jump performance when ES training is combined with sport training.

This is why the aim of the present study was to compare the effects of two different NMES training programs combined with sport training on the vertical jump performance. One training program was characterized by a high frequency, a short duration of stimulation and a long rest period and the other by a low frequency, a long duration of stimulation and a short rest period. The first was a typical force NMES training program for improving muscle strength and the second was a typical endurance NMES training program for improving muscle endurance.

Methods

Experimental Approach to the Problem

Twenty-seven volunteer male students in sport sciences, aged from 18 to 33 years old voluntarily participated in the experiment. They were randomized into 3 groups. Group F (n = 9) was stimulated (quadriceps femoris) with an 80 Hz current for 15 min for improving muscle strength, group E (n = 10) was stimulated (quadriceps femoris) with a 25 Hz current for 60 min for improving muscle endurance and group C (n = 8) was the control group (it did not perform neuromuscular electrical stimulation training). The height of the vertical jump was measured before neuromuscular electrical stimulation training (test 1), one week (test 2) and five weeks (test 3) after the end of the programs.

Subjects

The subjects' morphological characteristics (Table 1) showed no differences between the 3 groups (one-factor ANOVA). None of them had stopped practicing of sport during the six months prior to the study because of muscular/osteoarticular injury or any other reason. The subjects had not any previous experience of electrically evoked contractions. The experiment was conducted in the middle of academic year. All procedures were approved by the Local Medical Ethics Committee of our institution, and written consent from each subject was obtained as required.

Training

The subjects were randomized into 3 groups. The C group (n = 8) was the control group and did not perform NMES training. The two other groups (F and E groups) followed two different NMES training programs, composed of 3 NMES sessions a week over 5 weeks. NMES programs were performed with a portable stimulator delivering a maximal current intensity of 120 mA (CEFAR™ MYO 4®, Sweden). The F group (n = 9) underwent a typical force NMES training program ("force max 3" program of the stimulator) and the E group (n = 10) underwent a typical endurance NMES training program ("endurance 3" program of the stimulator). These programs included 3 periods: warm-up (10 mA, 5 Hz, 5 min), work-out ("force max 3": 15 min; "endurance 3": 60 min) and recovery (10 mA, 5 Hz, 15 min). Biphasic symmetrical rectangular-wave (450 microseconds) pulsed currents were used (ramp-up: 1.8 s; ramp down: 1.2 s). With the "force max 3" program, steady tetanic stimulations of 6 s (80 Hz current) were followed by pauses of 18 s during the work-out period, whereas 10 s steady tetanic stimulation (25 Hz current) were followed by pauses of 6 s with the "endurance 3" program. The intensity maximally tolerated by the subjects was delivered at each session (adjusted throughout the session) according to their pain threshold. The quadriceps muscles of both legs were stimulated with the subjects seated on a chair with a 90° knee flexion and a 110° hip flexion. Four self-adhesive conducting rectangular electrodes (Stimrode,® 50 × 89 mm, Sweden) were placed over each quadriceps. The two proximal electrodes were placed over the proximal part of the vastus medialis and vastus lateralis. The two distal electrodes were placed over the distal part of these muscles. All the subjects of the three groups continued their usual physical activity (also their usual diet) throughout the whole duration of the experience.

Testing

The vertical jump performance was tested on three occasions. The first (test 1) took place three days before the beginning of the training programs, the second and third (test 2 and test 3) took place one week and five weeks after the end of the training programs respectively. Test 2 allowed

Table 1. Comparison of the subjects' anthropometric characteristics between the 3 groups (one-factor ANOVA). None of the inter-group comparisons was significant ($p < 0.05$).

	Group F (n = 9)	Group E (n = 10)	Group C (n = 8)	Statistics p
Height (cm)	179.7 ± 7.5	176.6 ± 8.7	177.5 ± 5.1	NS
Body mass (kg)	70.6 ± 6.8	70.7 ± 9.3	73.6 ± 8.1	NS
Circumference of left thigh (cm)	47.8 ± 3.6	48.2 ± 3.4	48.6 ± 2.8	NS
Circumference of right thigh (cm)	48.2 ± 3.2	48.9 ± 3.3	47.8 ± 2.3	NS

evaluation of the adaptations induced by the NMES training and test 3 allowed the durability of these potential adaptations to be measured. During the NMES training and after the last session of NMES between test 2 and test 3, no subjects (three groups) was subjected to resistive training sessions to develop neuromuscular abilities (e.g. strength, power, speed). Before starting the evaluation sessions, the subjects performed a standard warm-up for 15 minutes on an ergocycle.

Vertical jump

The subjects performed vertical jumps (squat jumps) with the hands on the hips to minimize the contribution of the upper limbs. Vertical jumps started from a static semi-squatting position (90° knee flexion: to respect the specificity of the training position) which had to be maintained for 1 s before the jump. No counter-movement was allowed. The subjects performed six jumps, each jump being separated by a 10 s rest. The height of the jump was measured by a displacement sensor (Potentiometer DT/DT 420, PM Instrumentation,™ France; 200 Hz sampling frequency), which was attached to the subjects' waist, via a rigid belt. This height corresponds (see high part of Figure 1) to the difference between the height achieved on the way up (higher dotted line) and peak flat-footed standing height (lower dotted line). An instantaneous analysis of the curve on a micro-computer screen showed if the vertical jump was valid or not. A non-valid squat jump showed a slight counter-movement jump (starting from a standing position, squatting down and then extending the knee in a continuous movement). Figure 1 presents a valid and a non-valid squat jump. The best performance among the 6 trials was retained.

Statistical Analyses

The effects of each program were analyzed with a two-factor ANOVA (Analysis of Variance). The analysis studied the effects of the group factor (2 levels), the test factor (3 levels with repeated measures) and the interaction of the 2 factors (group*test interaction). When significant treatment effects occurred, Newman-Keuls post hoc analyses were used to test

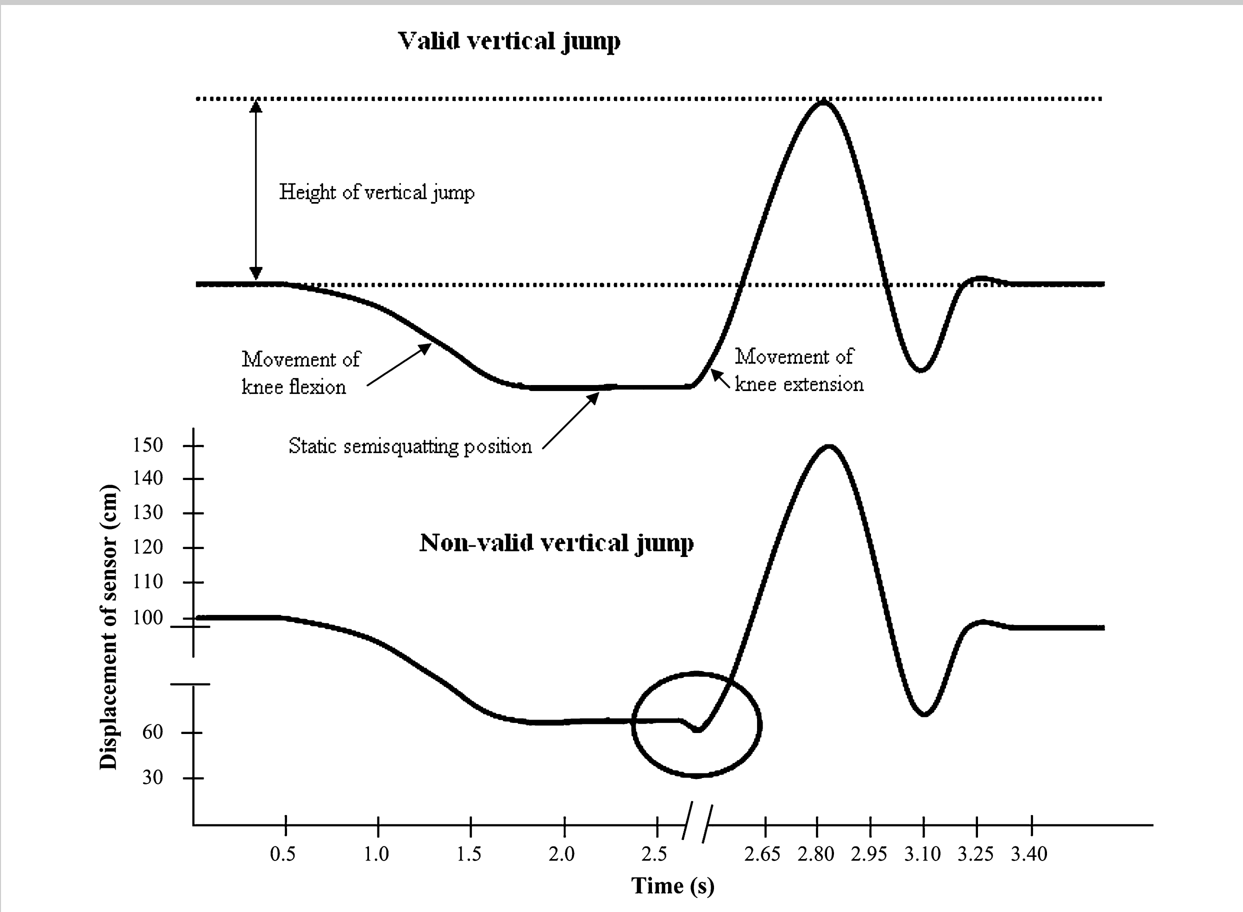

Figure 1. Graphic illustration of recordings showing representative trials of a valid and a non-valid vertical jump. For the non-valid jump, the circle illustrates a slight counter movement before the extension of the legs.

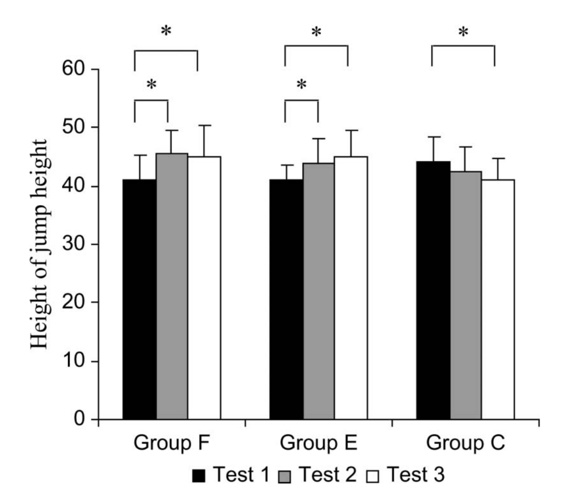

Figure 2. Mean values (± *SD*) of vertical performance (cm) for the three groups. * indicates a significant difference ($p < 0.05$) between the three different tests.

differences among means. The p value defined as significant was $p \leq 0.05$.

Results

Initially the vertical jump performance of the 3 groups was not significantly different (test 1). For all training sessions, the average intensity of the current was 60.8 ± 19.2 mA for group F and 67.6 ± 18.7 mA for group E. The difference of intensity between the two groups was not significant.

Figure 2 presents the results in vertical jump (mean values ± *SD*). Both the F and E groups significantly improved their vertical jump height between tests 1 and 2 ($p < 0004$; $p < 0.009$, respectively). For both groups F and E, vertical jump performances measured in test 3 were significantly better than those initially obtained in test 1 ($p < 0.001$; $p < 0.001$, respectively).

The performances were not significantly different between tests 2 and 3 for the three groups. The performances were not significantly different between tests 1 and 2 for group C. Nevertheless, its performance in vertical jump was significantly decreased between tests 1 and 3 ($p < 0.007$). At last, no group*test interaction (test 1 versus test 2; test 1 versus test 3; test 2 versus test 3) was significant.

Discussion

The aim of this study was to assess whether different NMES training programs could generate different effects on vertical jump performance. At the end of the programs, the subjects who were subjected to NMES programs (F and E groups) increased the height of the vertical jump.

According to Bosco et al. (4), the vertical jump assesses the muscular power of the subjects. As groups F and E increased their vertical jump height, one can consider that training with NMES led to an improvement of muscular power. Power being the product of force and velocity, our results could illustrate either an increase of the velocity parameter or an improvement of the force parameter. Maffiuletti et al. (18) observed a concomitant increase of the muscle strength and the height of the vertical jump. Thus, an increase of the muscle strength can induce an enhancement of the vertical jump performance. These authors explained this phenomenon by a possible greater number of motor units recruited after the NMES programs.

Nevertheless, we cannot exclude that the training programs performed in the present study induced an increase of the velocity parameter and thus, a faster muscle action. Indeed, with electrically evoked contractions, the mechanisms of muscle activation differ from those encountered with voluntary contraction. NMES causes an artificial synchronization of motor unit firing (9) which in, voluntary muscle action is non-synchronous. NMES training could induce a better synchronization of motor units firing during a voluntary movement (27).

Moreover, with voluntary muscle action, the order of motor unit recruitment goes from small motor units to large ones, in relation to the intensity of the stimulation - e.g. a submaximal voluntary muscular contraction recruits only small motor units (12)-. With NMES, large motor units are recruited before small motor units independently of the intensity of the current (28) even though this phenomenon may depend on the size and the morphological organization of the axonal branches located in the stimulation field (10). With healthy muscle, NMES tends to reverse the order of motor unit recruitment observed with voluntary contraction (7,13) and preferentially stimulates fast-twitch muscles with a larger fiber area. Hence, one can legitimately think that training programs with NMES could also lead to a better synchronization during muscle action especially in fast-twitch fibers, thus enhancing muscular power. Our results therefore suggest that training with NMES enables the development of specific neuromuscular adaptations transferable to a complex movement like a vertical jump when being combined with sport practice involving voluntary muscle actions.

Our findings also showed that the improvement in vertical jump could be maintained a long time after the last training session when subjects continued to follow their usual physical activity. Indeed, with both the F and E groups, the heights of the vertical jump measured in test 3 were significantly better than those initially measured in test 1. With basketball and volleyball players, Maffiuletti et al. (18,19) and Malatesta et al. (20) reported improvement in vertical jump that could be maintained up to two weeks after the last training session when using NMES programs which presented similarities to the "force max 3" program (NMES 3 times a week for

4 weeks with 100–120 Hz currents). Our results indicate that these improvements could be maintained longer, up to five weeks after the end of the program, suggesting that the combination of NMES and practicing of sport can induce durable neuromuscular adaptations.

Moreover, different NMES programs did not induce any specific adaptations on the vertical jump performance. Indeed, similar improvements were obtained when using two drastically different NMES programs: the "force max 3" program (high frequency, short duration of stimulation, long rest period) was devised to improve muscle contractility whereas the "endurance 3" program (low frequency, long duration of stimulation, short rest period) was conceived to enhance muscle endurance. Our results tend to show that with students in sport sciences without any previous experience of NMES, electrically evoked contractions with a low frequency current (e.g., 25 Hz) could improve muscular power, although tetanic fusion of fast-twitch muscle fibers is better obtained with a 35–65 Hz frequency (8). This result corroborates the findings of Balogun et al. (1) who showed, also with a maximally tolerated intensity, that the different frequencies used (i.e. 80, 45 and 20 Hz) did not change the gain amplitude of neuromuscular performance in different ways.

It is well known that to develop muscle contractility by NMES training it is necessary to apply a short duration of stimulation and a long rest period between each stimulation in order to minimize the effects of fatigue (11,15). Sport practice combined with a NMES program characterized by a long duration of stimulation and a short rest period between each stimulation could nevertheless improve their muscle contractility. A NMES training program destined to improve muscle endurance not only does not interfere with vertical jump performance but can even durably enhance it in the same way as a NMES training program destined to improve muscle strength. Moreover, the training-contraction intensity could also have influenced the results. Indeed, it is positively correlated with strength gains (26). Hence, the lack of difference concerning training-contraction intensity between the two groups could explain why their neuromuscular adaptations were similar.

Moreover, the results of the C group were somewhat surprising since they illustrated a significant decrease in the vertical jump performance between tests 1 and 3. This could be due to the period when our experiment was conducted, i.e., in the middle of academic year. Hence, one can hypothesize that the accumulation of practicing of sport may have led to a reduction of their muscle contractility since endurance exercise may inhibit signaling to the protein-synthesis machinery (23). Obviously, subjects from the F and E groups were similarly involved in sports. Nevertheless, these subjects did not react in the same way to the accumulation of practicing of sport as the control subjects since they benefited from NMES training, which even allowed them to improve their vertical jump performance.

Practical Applications

The present study showed that two different NMES training programs enhanced indifferently the vertical jump performance in male trained subjects. A NMES training program destined to improve muscle endurance does not interfere on vertical jump performance. It can even durably enhance it in the same way as a NMES training program destined to improve muscle strength. Thus, to improve muscle endurance without deteriorating muscle power, sportsmen can use electrical stimulation.

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References

1. Balogun, JA, Onilari, OO, Akeju, OA, and Marzouk, DK. High voltage electrical stimulation in the augmentation of muscle strength: effects of pulse frequency. *Arch Phys Med Rehab* 74: 910–916, 1993.
2. Bircan, C, Senocak, O, Peker, O, Kaya, A, Tamci, SA, Gulbahar, S, and Akalin, E. Efficacy of two forms of electrical stimulation in increasing quadriceps strength: a randomized controlled trial. *Clin Rehab* 16: 194–199, 2002.
3. Bobbert, ME and Van Soest, AJ. Effects of muscle strengthening on vertical jump height: a stimulation study. *Med Sci Sports Exerc* 26: 1012–1020, 1994.
4. Bosco, C, Luhtanen P, and Komi V. A simple method for measurement of mechanical power in jumping *Eur J Appl Physiol* 50: 273–282, 1983.
5. Boutelle, D, Smith, B, and Malone, T. A strength study utilizing the electro-stim 180. *J Orthop Sports Phys Ther* 7: 50–53, 1985.
6. Brocherie, F, Babault, N, Cometti, G, Maffiuletti, N, and Chatard JC. Electrostimulation training effects on the physical performance of ice hockey players. *Med Sci Sports Exerc* 37: 455–460, 2005.
7. Clamann, H, Gillies, J, Skinner, R, and Henneman, E. Quantitative measures of output of a motoneuron pool during monosynaptic reflexes. *J Neurophysiol* 37: 1328–1337, 1974.
8. De Bisschop, G, and Dumoulin, J. Neurostimulation électrique transcutanée antalgique et excito-motrice. Paris: *Eds Masson*, 1991.
9. Edwards, RHT, Young, A, Hosking, GP, and Jones, DA. Human skeletal muscle function: description of tests and normal values. *Clin Sci Mol Med* 52: 283–290, 1977.
10. Feiereisen, P, Duchateau, J, and Hainaut, K. Motor unit recruitment order during voluntary and electrically induced contractions in the tibialis anterior. *Exp Brain Res* 114: 117–123, 1997.
11. Hainaut, K and Duchateau, J. Neuromuscular electrical stimulation and voluntary exercise. *Sports Med* 14: 100–113, 1992.
12. Henneman, E, Somjen, G, and Carpenter, DO. Functional significance of cell size in spinal motoneurons. *J Neurophysiol* 28: 560–580, 1965.
13. Knaflitz, M, Merletti, R, and De Luca, CJ. Inference of motor unit recruitment order in voluntary and electrically elicited contractions *J Appl Physiol* 68: 1657–1667, 1990.
14. Kramer, JF. Effect of electrical stimulation current frequencies on isometric knee extension torque. *Phys Ther* 67: 31–38, 1987.
15. Lake, DA. Neuromuscular electrical stimulation. An overview and its application in the treatment of sports injuries. *Sports Med* 13: 320–336, 1992.

16. Laufer, Y, Ries, JD, Leininger, PM, and Alon, G. Quadriceps femoris muscle torques and fatigue generated by neuromuscular electrical stimulation with three different waveforms. *Phys Ther* 81: 1307–1316, 2001.

17. Laughman, RK, Youdas, JW, Garrett, TR, and Chao, EYS. Strength changes in the normal quadriceps femoris muscle as a result of electrical stimulation. *Phys Ther* 63: 494–499. 1983.

18. Maffiuletti, NA, Cometti, G, Amiridis, IG, Martin, A, Pousson, M, and Chatard, JC. The effects of electromyostimulation training and basket practice on muscle strength and jumping ability. *Int. J Sports Med* 21: 437–443, 2000.

19. Maffiuletti, NA, Dugnani, S, Folz, M, Di Pierno, E, and Mauro, F. Effect of combined electrostimulation and plyometric training on vertical jump height. *Med Sci Sports Exerc* 34: 1638–1644, 2002.

20. Malatesta, D, Cattaneo, F, Dugnani, S, and Maffiuletti, NA. Effects of electromyostimulation training and volley practice on jumping abilities. *J Strength Cond Res* 17: 573–579, 2003.

21. McMiken, DF, Todd-Smith, M, and Thompson, C. Strengthening of human quadriceps muscles by cutaneous electrical stimulation. *Scand J Rehab Med* 15: 25–28, 1983.

22. Miller, C and Thepaut-Mathieu, C. Strength training by electro-stimulation conditions for efficacy. *Int J Sports Med* 14: 20–28, 1993.

23. Nader, GA. Concurrent strength and endurance training: from molecules to man. *Med Sci Sports Exerc* 38: 1965–1970, 2006.

24. Parker, MG, Bennett, MJ, Hieb, MA, Hollar, AC, and Roe, AA. Strength response in human femoris muscle during 2 neuromuscular electrical stimulation programs. *J Orthop Sports Phys Ther* 33: 719–726, 2003.

25. Romero, JA, Sanford, TL, Schroeder, RV, and Fahey, TD. The effects of electrical stimulation of normal quadriceps on strength and girth. *Med Sci Sports Exerc* 14: 194–197, 1982.

26. Selkowitz, DM. Improvement in isometric strength of the quadriceps femoris muscle after training with electrical stimulation. *Phys Ther* 65: 186–196, 1985.

27. Singer, KP. Functional electrical stimulation of the extremities in the neurological patient: a brief review. *Austr Physiother* 33: 33–42, 1986.

28. Solomonow, M. External control of the neuromuscular system. *IEEE Trans Biomed Eng BME* 31: 752–763, 1984.

29. Soo, CL, Currier, DP, and Threlkeld, AJ. Augmenting voluntary torque of healthy muscle by optimization of electrical stimulation. *Phys Ther* 68: 333–337, 1988.

30. Stefanovska, A and Vodovnik, L. Change in muscle force following electrical stimulation: dependence on stimulation waveform and frequency. *Scand J Rehabil Med* 17: 141–146, 1985.

31. Wolf, SL, Ariel, GB, Saar, D, Penny, MA, and Railey, P. The effect of muscle stimulation during resistive training on performance parameters. *Am J Sports Med* 14: 18–23, 1986.