Brief Paper : Physiology

Effect of Repetitive Biphasic Muscle Electrostimulation Training on Vertical Jump Performances in Female Volleyball Players

Tanguy Marqueste, Folly Messan, Francois Hug, Jérôme Laurin, Erick Dousset, Laurent Grelot and Patrick Decherchi*

Institut des Sciences du Mouvement: Etienne-Jules MAREY (UMR CNRS 6233)
Université de la Méditerranée (Aix-Marseille II)
Parc Scientifique et Technologique de Luminy
Faculté des Sciences du Sport de Marseille
Case Postale 910-163, avenue de Luminy
13288 Marseille Cedex 09, France.
E-mail: patrick.decherchi@univmed.fr
[Received June 27, 2008; Accepted March 10, 2010; Published online April 7, 2010]

The aim of this study is to describe the effects of transcutaneous muscular electrical stimulation on vertical jump performance (jumping height). Electromyostimulation (30 min/day, 10 sessions during 4 weeks) was applied, using a symmetric and biphasic rectangular pulses, with ramp modulation of both pulse duration and stimulation frequency. Ten healthy young women received this electrical stimulation program of the two thigh muscles (*Vastus Lateralis or Biceps Femoris*) and five unstimulated women were in a control group. Effects of the functional electrical stimulation were evaluated before, during the stimulating protocol, then a 4-week follow-up was performed after the end of exercises and stimulations protocols. Two different vertical jumps were carried out (squat and counter movement jumps). Performances were increased in all electrostimulated groups from the first week. These gains were still observed 4 weeks after the end of the protocol when the *Vastus Lateralis* muscles were electrostimulated.

These results suggest that chronic electrical stimulation induces durable changes on the motor unit recruitment and performance when appropriate muscles were stimulated, and stimulation of thigh muscles weakly involved in jump is followed by a temporarily increase in performance that decreases immediately after the end of electrostimulation, maybe due to placebo effect.

Keywords: Squat Jump, Counter Movement Jump, Functional Electrostimulation, Placebo

1. Introduction

Electromyostimulation (EMS) also called functional electrical stimulation (FES) is mainly used in rehabilitation programs when the neuromuscular function has been injured, and also as a sport training method. It has been used in swimming, basketball, volleyball or cycling practices involving *Latissimus Dorsi*, *Quadriceps*, *Vastus Lateralis* (VL) or *Triceps Surae* muscles respectively. EMS results in a reversal of recruitment order of the motor units with a preferential activation of the largest motor units first (Enoka, 1988) and a possible preferential adaptation of the type II motor units (Maffiuletti et al., 2000).

Previously, Maffiuletti et al. (Maffiuletti et al., 2000), using EMS combined with plyometric training reported an improvement of vertical jump ability in male volleyball players and a rapid increase of the knee extensors and plantar flexors maximal strength. These adaptations were then followed by an improvement of the specific jumping ability, likely to affect performance on the short term. Then, complementary of EMS sessions with a specific work out (i.e. plyometric) allowed to obtain beneficial effects. In our previous study (Marqueste et al., 2003), we observed an increase in strength after an EMS training of *Rectus Femoris* (RF) and *Flexor Digitorum* (FD) muscles associated with a lack of M-wave alterations, suggesting that the EMG parameters changes (root mean square and median frequency) did not result from eventual muscle membrane excitability alterations, but more probably from some changes in the motor units recruitment.

The purpose of this study was to determine if a 4-week electromyostimulation training with a specific current, previously described to have beneficial effects on animal and Human muscles (Marqueste et al., 2002, Marqueste et al., 2003), could increase jump performance during the pre-season training in volleyball athletes.

2. Materials and Methods

2.1. Subjects

Fifteen healthy trained women (age: 20.6±1.3 years, height: 1.68±0.05 m, weight: 62.0±5.0 kg) participated at this study. They were randomly assigned in three groups: the control group (n=5, without EMS), the sham (placebo) group (n=5, EMS was applied on the *Biceps Femoris* muscles) and the EMS group (n=5, EMS was applied on the *Vastus lateralis*). These aforementioned groups were designated as Control, BF and VL groups. It had been previously shown that the VL muscle was in half part involved (50%) in the jumping performance (Hubley and Wells. 1983). Thus, the quadriceps muscles are necessary during squat jump (SJ) and counter movement jump (CMJ) contrary to the non-implication of *Biceps Femoris* muscles. Biceps Femoris (BF) muscle has two heads: the long head arises from the lower and inner part of the ischium, and from the lower part of the sacrotuberous ligament. The short head arising between the adductor magnus and vastus lateralis, is really small (about 5 cm) and located just above at the popliteal area (Netter 2006). Due to its size and position, this latter is not stimulated during our EMS protocol. However both heads of the BF perform knee flexion. Since the long head originates in the pelvis it is also involved in hip extension, but the long head is a weaker knee flexor when the hip is extended (because of activation insufficiency). For the same reason the long head is a weaker hip extender when the knee is flexed. During squat jump (SJ) or counter movement jump (CMJ) the subjects were asked to maintain a vertical position of the trunk (i.e. extension of the hip) and to induce a knee flexion during CMJ or to maintain this position before SJ. Therefore we choose the BF muscle on purpose in order to investigate a sham-placebo effect of EMS on muscle weakly involved our studied movement.

All subjects were involved in volleyball training program at the university during 4 hours per week and were in pre-season training at the time of the protocol. The possible risk of harm or pain due the protocol were previously explain in a clear document in accordance with the local ethical commission of the *Université de la Méditerranée (Aix-Marseille II)* who gave its permission.

2.2. Electromyostimulation

Muscles were stimulated during 10 sessions of 30 min distributed on a 4-week period. As we previously described (Marqueste et al., 2002), the stimulation pattern consisted in a biphasic and symmetric (the wave having consecutive and symmetrical positive and negative peaks) pulse current (around 100 V, i.e. daily adjusted by each subjects in order to have maximal but not painful contraction) with a ramp modulation of frequency (means gradual and linear increase of frequency from 4 to 75 Hz and decrease to 4 Hz) and pulse duration (400-100-400 μs). Each stimulation pattern lasted for 11-s and it was repeated twice a minute with a rest of 19-s between each stimulation. *Biceps Femoris or Vastus Lateralis* muscles from the both legs were stimulated. EMS was delivered through a clinical stimulator (Multiprocess 16+, Physitech®, Electronique Medicale Marseille, France) used for electrophysiotherapy and kinesitherapy. The stimulating electrodes were placed on the motor point of each muscle defined as the point on the surface of the skin over the muscle belly at where the smallest amount of current is required to produce muscle contraction. The surface of the electrodes were 3×5 cm with 5 cm inter-electrode distance (center to center); the anode being over the muscle endplate estimated at the middle of the muscle belly and the cathode above, with and impedance value adjusted and measure between 0.5 and 1 MΩ by cleaning skin surface with alcohol and ether. Concentric contractions were elicited by EMS.

2.3. Vertical jumps

Subjects were tested before (week 0), at the beginning and at the end of each session during the

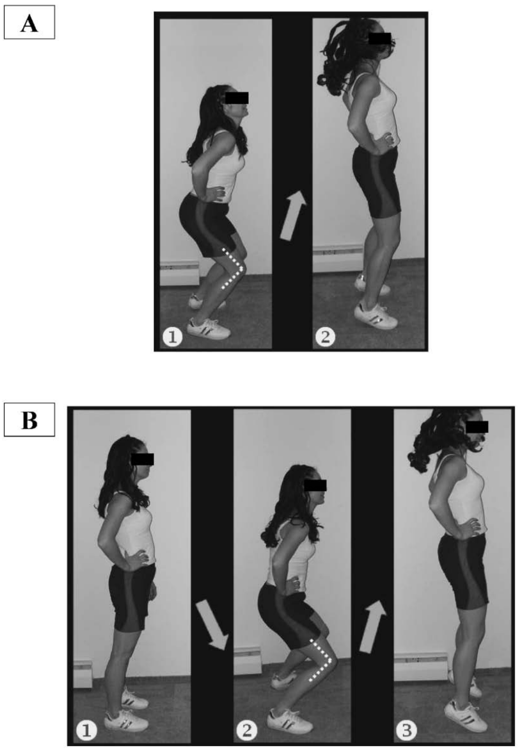

Figure 1 Squat (SJ) and Counter Movement (CMJ) Jump.
A. The two steps of the SJ: ① starting from a static semisquatting position maintained 1-s without movement, then ② jump in pure concentric contraction of lower limb muscles.
B. The three steps of the CMJ: ① starting from a stand up position, ② squatting down and then ③ extension in one continuous movement. Extensor muscles involved are first stretched and then shortened to accelerate the body or limb. This action of the muscles is called a stretch shortening.
We can note that during the jump, the hands were kept on the hips to minimize the contribution of the upper limbs.

program (week +4) and once again 4 weeks after the last training session (week +8). A standardized warm-up, lasting 5 min, was carried out before each testing session and consisted of several contractions of the lower limb muscles (i.e. squat, leg extension and jump). Subjects 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 semi squatting position (90° of flexion) maintained for one second without any preliminary movement (SJ) **(Figure 1A)**; counter movement jump starting from a standing position, squatting down and then extension in one continuous movement (CMJ) (**Figure 1B**). An electronic timer was connected to an optical acquisition system for measuring the flight time (Optojump®, Microgate, Bolzano, Italy). The time onset was triggered by the unloading of the jumpers' feet from the ground and was stopped at the moment of the touch down. The height (h) of jump was then calculated by using the flight time (t) of the respective jumps ($h = 1/8.g.t^2$). Jumpers were asked to jump as high as they could. In order to avoid difference of limb posture that could lead to the difference of flight time, we verify with a video recording (Numerical camcorder Canon™, MV 830i, Unterschleissheim, Germany) linked to a walking track apparatus (Simi-Motion® software, 50-Hz acquisition frequency, Unterschleissheim, Germany) that the postures of the lower limb were identical between at the take-off and at the landing and between pre-training and post-training. Three trials of each SJ and CMJ were measured, with a 3-min rest between jumps. The best performance was retained and included in subsequent analysis.

2.4. Statistical analysis

Data processing was performed by using a software program (SigmaStat®, Jandel, Chicago, Illinois, USA) on the raw values. Data are presented as mean ± SEM. An analysis of variance on repeated measures was used to assess the effect of the training program at week 0, over the 10 sessions during the training program, then at week 8. Student-Newman-Keuls *post-hoc* tests were used to analyze the differences. A difference was accepted as statistically significant when $p < 0.05$.

3. Results

After 4 weeks of stimulation, SJ (BF: 23.5 ± 2.4 cm and VL: 30.3 ± 3.9 cm) and CMJ (BF: 28.9 ± 2.2 cm and VL: 34.6 ± 4.2 cm) heights are significantly increased compared to pre-training values [SJ (BF: 20.2 ± 2.7 cm and VL: 23.8 ± 3.3 cm), CMJ (BF: 22.2 ± 2.9 cm and VL: 28.15 ± 3.5 cm)]. For the SJ, performance increases were +16.4 ± 2.4% (BF) and +26.9 ± 3.8% (VL) whereas for the CMJ, increases were +30.2 ± 2.1% (BF) and +23 ± 4.2% (VL).

Except for the control group (**Figure 2A**), SJ ability was significantly increased from the first week in the VL group (+11.1 ± 4.8%) and surprisingly in the placebo BF group (+16.4 ± 2.9%). These significant gains in vertical jump height were maintained during the 4 weeks of the volleyball training plus EMS; the VL group conserving significant gain (+26.5 ± 4.3%) 4 weeks after the end of the EMS training (**Figure 3A**).

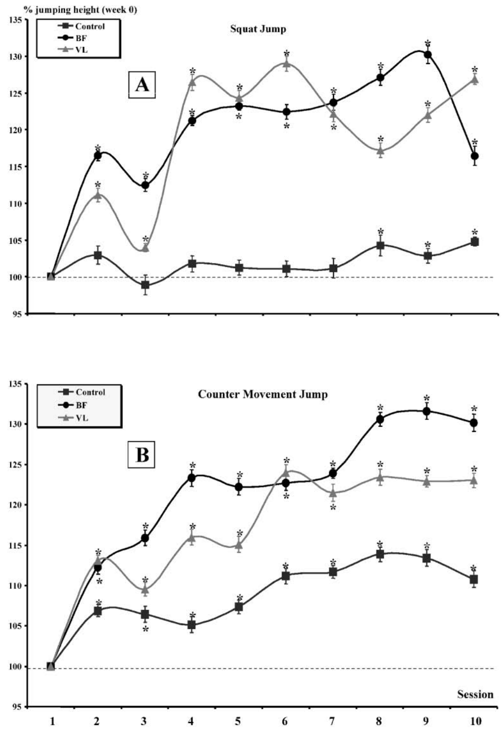

Figure 2 Evolution of the jumping height values during a 4 weeks training period (10 sesions) with an electromyostimulation protocol. Electrical stimulation was applied to the Biceps Femoris (BF) or Vastus Lateralis (VL) muscles. Control group received no stimulation.
A. Squat Jump (SJ).
B. Counter Movement Jump (CMJ).
Asterisks indicate a significant difference ($p < 0.05$) compared to the height values recorded in pre-test (week 0) session.

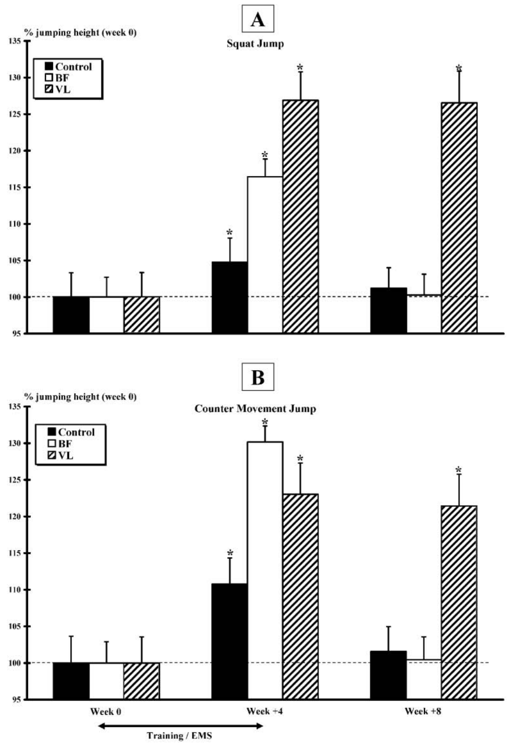

Figure 3 Comparison of the jumping height values between the pre-test (week 0), the post-test (week +4) and the delayed-test (week +8, i.e. 4 weeks after the end of the electromyostimulation protocol). Electrical stimulation was applied to the Biceps Femoris (BF) or Vastus Lateralis (VL) muscles. Control group received no stimulation.
A. Squat Jump (SJ).
B. Counter Movement Jump (CMJ).
Asterisks indicate a significant difference ($p < 0.05$) compared to the height values recorded in pre-test (week 0) session.

Heights measured during the CMJ presented a significant increase from the first week in the both electrostimulated (VL: +12.3±2.3% and BF: +13.1±4.8%) and control (+6.9±3.8%) groups (**Figure 2B**). The effect persisted 4 weeks after the end of the EMS training program only in the VL group (+21.4%) (**Figure 3B**).

4. Discussion

The present study indicated that EMS training before a volleyball training season improves the performance in the vertical jump. The main findings of this study demonstrated that a 4-week EMS program during the volleyball pre-season training significantly increased the height of different vertical jumps as compared to the sole pre-season training. More surprisingly, the present study shows an increase in the jumping performance even when Biceps Femoris muscle, poorly involved in these jumps, was stimulated. However, gains observed in vertical jump performance were lost as soon as the EMS session was stopped. Thus, it seems that EMS could act on motivational pathways, i.e., the placebo effect could be responsible in this temporary performance increase.

EMS (Maffiuletti et al., 2000), weight or plyometric training alone or combined (weight/plyometric or EMS/plyometric)(Maffiuletti et al., 2002) increased significantly vertical jump heights. Maffiuletti et al. (Maffiuletti et al., 2000) reported in basketball player a significant increase in SJ performance after a 4-week EMS training program; the CMJ performance remained unchanged. In our study, we observed also an increase in CMJ performance during the 4-week EMS period, remaining high one month after the end of EMS. This discrepancy between our results and those of Maffiuletti et al. (Maffiuletti et al., 2000) could be explain by the fact that our subjects were 1) volleyball players and 2) involved in a pre-season training program. During CMJ, the muscles are stretched while they were actived. As a result of this muscular lengthening, potential energy is stored in the elastic component and then released during the subsequent shortening. Maffiuletti et al. (Maffiuletti et al., 2000) suggested that improvements in strength of muscles involved in complex movements using elastic energy, such as CMJ, require a longer period of specific training before beneficial effects are observed in jumping performance and that EMS training is not specific to develop elastic behaviour of skeletal muscle. However, these authors also reported an increase in jumping height during CMJ when they associated EMS with plyometric jumps training. In our study, the immediate increase in jumping performance during CMJ could be due to a specific pre-season training program used by our volleyball players or by apprenticeship of a new specific and unusual jump from our subjects. This can be confirmed by the rapid increase in jump performance during CMJ in the control unstimulated group and the reduced difference in height observed with the two EMS groups (**Figure 2B**).

Several authors reported that the percentage of fast twitch fibers in a muscle was an important factor for force development during maximal static efforts (Thorstensson et al., 1976) suggesting that EMS training increased the activation and thus the contribution of the fast twitch muscle fibers (Enoka, 2002), only able to develop the highest force during maximal voluntary contraction. Except in paralysed or partially paralysed subjects, EMS opposes the physiological recruitment order of motor units found during a voluntary contraction, in which, according to the Henneman' size principle; the smallest motoneurons (supplying the type I muscle fibers) are first activated (Enoka, 2002). During such EMS condition, recruitment order depends on 1) the characteristics of the current used (Thorstensson et al., 1976), 2) the distance between the stimulating electrode and the peripheral axon, i.e., the larger axon of the largest diameter motor units are often superficially located in the muscle or the axon collaterals, i.e., the axon excitation threshold being inversely proportional to its diameter (Enoka, 2002) 3) the activation of the cutaneous and proprioceptive afferents (''feedback effects''). The marked attenuation of the changes in RMS (Root Mean Square) during fatiguing efforts immediately after the EMS training (Marqueste et al., 2003), and their persistence 4 weeks after the end of the training, could be interpreted as a long-term facilitation occurring in the central nervous system elicited by some changes in the afferent pathways arising from the stimulated muscles, and 4) the changes induced by the EMS (proportions, metabolic and contractile properties of the muscle fibers).

During a maintained voluntary static contraction the force failure is associated with a MF (Median Frequency) decline and a RMS increase, indicating a neuromuscular fatigue. After EMS training (Marqueste et al., 2003), the analysis of 60% MVC trials during the post-tests showed a median frequency decline and also a non significant RMS increase. The attenuation of EMG signs of neuromuscular fatigue was associated with an increased in MVC. Montes-Molina et al. (Montes Molina et al., 1997) suggested that electrical stimulation produces immediate changes on the motor unit: increasing the recruitment number of fibers, namely a selective recruitment of type II fibres, and also their action potential velocity. After a 10-day EMS period, they reported a significant changes in the MF and RMS, measured during exercise. Due to the absence of changes in M-wave duration in our previous protocol using the same stimulating current, this explanation could be discarded. Indeed, as previously reported, the duration of M-wave should be then reduced, and the intramuscular conduction velocity should increase. We also suggested the EMS-induced changes in the EMG response to sustained static voluntary effort was due to the occurrence of an enhanced aerobic pathway with EMS that should reduce the intra-muscular release of metabolites, including the lactate. This should reduce the activation of the free ending chemosensory muscle afferent fibers (the group III and IV afferents fibers) which are supposed to trigger the EMG changes during fatiguing efforts, namely the power spectrum shift towards the lowest frequencies. The last explanation would be that EMS could have elicited some specific changes in the excitability of this muscle afferents endings, namely in their capability to detect the metabolic variations preceding fatigue.

EMS training is responsible for a durable neuromuscular functional adaptation which persisted for several weeks after the end of the training. A preferential recruitment of the fast twitch muscle fibers during EMS could be responsible of these supposed changes in the central neural drive but could also involve some changes in the chemosensitive afferent muscle pathways. Therefore, EMS training remains a method to enhance the performance and could be used during the pre-season training to enhance vertical jump performance without interfering with training; player's abilities being maintained at a high level after the end of the EMS program.

Acknowledgements

We are grateful to Frédéric GOUNARD (Physitech®, Electronique Médicale) and, Francis BERTHELIN, Ferdinand TAGLIARINI (Faculté de Médecine Nord, Marseille) for technical assistance and ALARME (Association Libre d'Aide à la Recherche sur la Moelle Epiniere), and DGA-DSP (Délégation Generale pour l'Armement, n° 00.34.029.00.470.75.01) for grants.

References

Enoka, R. M. (1988). Muscle strength and its development. New perspectives. Sports Med. 6: 146-168.

Enoka, R. M. (2002). Activation order of motor axons in electrically evoked contractions. Muscle Nerve. 25: 763-764.

Hubley, C. L. & Wells, R. P. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. Eur J Appl Physiol Occup Physiol. 50: 247-254.

Maffiuletti, N. A., Cometti, G., Amiridis, I. G., Martin, A., Pousson, M., & Chatard, J. C. (2000). The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. Int J Sports Med. 21: 437-443.

Maffiuletti, N. A., Dugnani, S., Folz, M., Di Pierno, E., & Mauro, F. (2002). Effect of combined electrostimulation and plyometric training on vertical jump height. Med Sci Sports Exerc. 34: 1638-1644.

Marqueste, T., Decherchi, P., Dousset, E., Berthelin, F., & Jammes, Y. (2002). Effect of muscle electrostimulation on afferent activities from tibialis anterior muscle after nerve repair by self-anastomosis. Neuroscience. 113: 257-271.

Marqueste, T., Hug, F., Decherchi, P., & Jammes, Y. (2003). Changes in neuromuscular function after training by functional electrical stimulation. Muscle Nerve. 28: 181-188.

Montes Molina, R., Tabernero Galan, A., & Martin Garcia, M. S. (1997). Spectral electromyographic changes during a muscular strengthening training based on electrical stimulation. Electromyogr Clin Neurophysiol. 37: 287-295.

Netter, F. H. (2006). Atlas of Human Anatomy, 4th Edition. Saunders.

Thorstensson, A., Grimby, G., & Karlsson, J. (1976). Force-velocity relations and fiber composition in human knee extensor muscles. J Appl Physiol. 40: 12-16.

Name:
Patrick Decherchi

Affiliation:
University of the Mediterranean-Aix-Marseille II (France)

Address:
UMR CNRS 6233-Institute of Movement Sciences

Brief Biographical History:
39 international publications

Main Works:

- Anatomical and functional plasticity of the central and peripheral nervous system

Membership in Learned Societies:

Patrick DECHERCHI is Assistant Professor of Physiology and director of studies of the master degree of ''*Sciences and Technologies of Human Movement*'' (SMTH) at the Faculty of Sport and Sciences in the University of the Mediterranean (Aix-Marseille II, France) since 1999. He is the head of the team ''*Plasticity of Neural and Muscular Systems*'' (PSNM) in the Institute of Movement Sciences (UMR CNRS 6233, University of the Mediterranean-www.ism.univmed.fr). He obtained his Ph.D. in ''*Neuroscience*'' (Neurobiology/Neurophysiology) in 1996. Immediately after his Ph.D., he worked for one year for the French Military Ministry as Engineer. From 1997 to 1999, he was Research Associate at the National Institute for Medical Research (Division of Neurobiology, UK) in London. His research topics concern the anatomical and functional plasticity of the central and peripheral nervous system.