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Original Article

Acute effects of lower body electromyostimulation application with two different frequencies on isokinetic strength and jumping performance

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Abstract:

Electromyostimulation is commonly used for potentiation of muscle strength to supplement voluntary muscle contractions. However, the acute effects of the lower body electromyostimulation on muscle strengthening are poorly known. Fourteen moderately trained men exposed to three lower body electromyostimulation sessions in nonconsecutive days under experimental conditions (30Hz, 100Hz) and control condition (0Hz). Each subject participated in post-tests including squat jump, countermovement jump and dominant concentric knee extension-flexion isokinetic strength at 60, 180, 300ºs-1. All tests performed 90 seconds after a single bout of lower body electromyostimulation with 90º static squat position for 16 seconds (4s Electromyostimulation/4s rest) at maximal tolerated current intensity. Statistical analysis have shown that there are significant increases in jump heights ($p<0.05$), rating perceived exertion ($p\leq0.001$) and knee flexion torques at 180 and 300ºs-1 angular velocities ($p<0.05$) for acute electromyostimulation with two experimental conditions compared to control condition. Postactivation potentiation effect of conditioning contractions can be responsible for mechanism under these significant differences. However, there were no significant differences between low and high frequencies regarding 60º, 180º, 300ºs-1 extension and 60ºs-1 flexion knee isokinetic torques ($p>0.05$) and all jump values ($p>0.05$). In conclusion, lower body electromyostimulation at low or high frequencies can increase explosive strength regarding high-speed flexion torques and jump height in acute phase of moderately trained men.

Keywords: acute effect, electromyostimulation, ısokinetic strength, jump performance, perceived exertion, Potentiation

Introduction

The possibility to generate contractile activity of a muscle with an electrical current application on the neuromuscular system has been known since the 18th century (Bax et al., 2005; Vanderthommen and Duchateau, 2007). The number of Electromyostimulation (EMS) studies has been enlarged in the last 30 years on healthy individuals and EMS has been paid attention as a new training method for athletes. Yakov Kotz has claimed that increased muscle strength (~%40) after short-term EMS training program with high frequency caused this interest. There are a lot of studies (Strauss and Domenico, 1986; Holcomb, 2005; Kraemer and Mendryk, 1982; Komi, 2008; Porcari et al., 2002; Walmsley et al., 1984; Yanagi et al., 2003) supporting or opposing these results in literature.

High-frequency EMS training has increased its popularity as a method of strength training to increase maximal voluntary strength of the lower limb muscles among healthy individuals and elite athletes in the last few years (Maffiuletti et al., 2002a; Maffiuletti et al., 2002b; Malatesta et al., 2003; Marqueste et al., 2010; Taifour et al., 2013). EMS has been accepted to be an important complement in rutin strength training programs for the enhancement of athletic performance (Thorstensson et al., 1976) because it can provide more intense contraction to the stimulated muscle and thereby induce greater adaptive responses (Borniquez et al., 1993; Maffiuletti et al., 2000). LB-EMS application is an effective training method to enhance lower body power that provides intense contraction to the stimulated leg muscles and thereby induces greater adaptive responses. Local EMS application have shown positive effects on neuromuscular parameters in athletes and healthy individuals; however; there are a few multi-joint EMS studies on the effects of athletic performance and therefore, the feasibility and acceptability of this new training technology have turned out to be an important point (Kemmler et al., 2012; Kraemer and Mendryk, 1982; Kale et al., 2014; Komi, 2008, Vanderthommen and Duchateau, 2007; Porcari et al., 2002).

Acute EMS applications produced the similar physiological effects as conventional aerobic exercises. Some studies have indicated that EMS training combined with aerobic exercises cause more energy consumption (%17) than aerobic exercises (Kemmler et al., 2012; Hennessy et al., 2010). Therefore it is necessary to study on the acute effects of EMS application on explosive power performances. In different EMS protocols, theoretically, partial or complete neuromuscular adaptations seem possible, but the physiological effects are

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different from each other. Also acute and chronic effects of EMS are still not clear. There are limited studies on the effect of a single EMS training session on isokinetic strength and jumping performance. The purpose of the present study was to investigate the acute effects of a lower body electromyostimulation (LB-EMS) bout on maximal isokinetic strength of the dominant knee extensor-flexor muscles and vertical jumping performance.

Materials and Methods

In these study vertical jump including squat jump (SJ) to assess explosive power and counter movement jump (CMJ) to assess elastic strenght performance of the lower extremity are tested. Maximal isokinetic strength test of the knee extensor-flexor muscles at different angular velocities is also an acceptable test to evaluate leg power. Heights of SJ and CMJ, and isokinetic maximal knee extensor-flexor torque values at three angular velocities were assessed to examine the acute effects of LB-EMS during static squat movement. A randomized crossover trial with moderately trained men was used to address the hypothesis of the acute effect of LB-EMS during static squat movement on jumping performance and knee extensor-flexor torque values at three angular velocities (60, 180 and 300°/s) of two different frequencies (low=30Hz and high=100Hz) with the control condition frequency (0Hz). The current protocol allowed each subject to serve as his own control.

Participants

Fourteen moderately healty trained men, who routinely perform moderate intensity exercises at least four times a week and 2-2.5 hours a day, voluntarily participated into the study. Descriptive statistics of the subjects are given in the Table 1. The subjects were instructed not to be involved in any additional exercise and not to consume any alcohol and caffeine. They had an ordinary pretraining diet for at least 24 hours before measuring and testing sessions. Subjects were advised to be properly hydrated (~500ml) one hour before testing. The laboratory temperature ranged from 23 to 25°C during the tests. The study protocol was conducted in compliance with the declaration of Helsinki and the study started after obtaining ethical approval from the local ethics committee of Osmangazi University. Subjects having any injury risk were not included in this study. All subjects were informed about the study protocol. The participants were notified about the potential risks and benefits of the study and their written informed consent was taken.

Volunteers were recruited in some regional high schools and colleges in the city of Eskişehir, in Turkey. Volunteers inclusion and exclusion criteria were established by the researcher before the beginning of the study. Researchers screened volunteers using the following inclusion criteria from previous the study: (1) they were selected from among healthy men, (2) age range is 13-26 years, (3) they have been doing physical activity regularly at a moderate effort at least 2 years. Also, volunteers were excluded from the stuty for the following reasons: (1) participating in any kind of experimental EMS studies, (2) having any risk of heart disease, (3) epilepsy, (4) transient ischemic attack, (5) history of no stroke and these kind of neurological disorders, (6) open wounds, (7) using of pacemaker and (8) having any health problems.

Table 1. Descriptives of participants (n=14)

Variables	**Mean ± SD**
Age (year)	19.5±6.7
Height (cm)	180.9±7.9
Weight (kg)	71.5±14.6
Body Mass Index (kg.m^{2-1})	22.0±3.7
Body Fat Percentage (%)	16.4±3.8
Exercise Volume (h.wk^{-1})	9.1±1.5
Exercise Backround (year)	7.7±5.8
Rest Heart Beat (beat.min^{-1})	75.2±11.6

Procedures

All of the subjects participated into the study underwent LB-EMS applications at two different frequencies of low (30Hz) and high (100Hz), and also control condition frequency (0Hz) in a random order. The measurements and tests were made at the same time of the day in view of the chronobiological effects (09:00-12:00am). Each subject participated in the same test conditions (0, 30 and 100Hz), a standart test day started with warm-up session. After these session, tests were perfomed with SJ and CMJ and then dominant isokinetic knee flexion/extension strength tests were taken. After that three days rest was given at least between each condition tests and all measurements and all LB-EMS applications in these study were completed in a total of 17 days. The subjects participated in all the testing and the LB-EMS implementation to familiarize with the trial one week before having the test session. Subjects performed all of the three experimental sessions (30Hz, 100Hz, and 0Hz) having at least one day off between the sessions. Each subject performed all measurement and test sessions according to the study protocol. Maximal intensity comfortably tolerated at 30Hz and 100Hz frequencies of LB-EMS applications for each subject were determined during the familiarisation period. Subjects had 90s rest on sitting position after the end of the LB-EMS application. Squat jump (SJ) and counter movement jump (CMJ) tests were performed with a wireless jump assessment device right after it (Freejump, Sensorize, Italy). Ninety seconds after the end of jumping tests, subjects performed isokinetic strength tests with dominant knee knee extensor-flexor muscles at three angular velocities (60, 180 and 300º/s) with an isokinetic dynamometer (Humac Norm Testing & Rehabilitation System, USA). Verbal encouragement and required feedback were given to each participant during each measurement, test, and LB-EMS application. In addition, the ratings of perceived exertion during the LB-EMS application and the control condition frequency were determined with Borg Scale (RPE; 6-20 Borg scale). Flow chart of the study design is given at Figure 1.

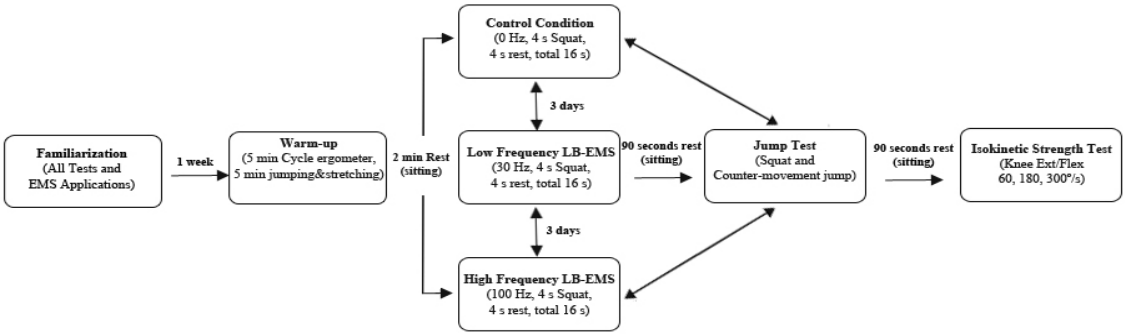

Fig. 1. Flow Chart of The Study

Lower body EMS application

Initially, anthropometric measurements were taken after 10min warm-up implemented with 5min unloaded pedaling a cycle ergometer and then 5min various stretching and jumping exercises, respectively. The strip electrodes (44x4cm for the thigh region and 27x4cm for calf region) were placed on the area of thigh and calf muscles during the 2 minutes rest period after the warm-up session. Then, 16s EMS application was applied bilaterally with an EMS application device (Miha Bodytec, Germany) at the maximal tolerated comfortably current intensity that specified in the trial and familiarisation period. The current was applied to 4s with 4s rest intervals with the specific current parameters that was described in the Table 2. None of the subjects reported any serious discomfort during EMS application. Each subject retained the 90º static squat-position (Figure 2.) throughout the LB-EMS application and rested in standing position during the rest intervals.

Fig.2. The 90º static squat LB-EMS position

Table 2. Electrical current parameters

Current Parameters	EMS Application Settings
Stimulation Frequency	30Hz / 100Hz
Pulse Duration	4s
Current Break	4s
Current Breadth	400µs
Current Type	bipolar
Duration	16s
Ramp-up Time	0s
Current Intensity	100% maximal tolerated

Data collection and analysis

Anthropometry and body fat percentage measurements

Height was measured to the nearest +0.1cm between head's vertex point and foot using a wall mounted stadiometer (Holtain Ltd, UK) after a deep inspration. The subjects without shoes wore short, t-shirt, and head at frontal plane. Body weight and body fat percentage were measured with bioelectrical impedance analyser (Tanita MC 180MA, Japan). Body weight was measured to nearest +0.1kg and during body fat percentage measurements subjects without shoes wore short and they kept eyes forward in standing position. All the measurements were taken two times by the same researcher and the mean values were recorded.

Jumping tests

Subjects were rested 90s in sitting position at the end of LB-EMS. The rest period after, squat jump (SJ) and counter movement jump (CMJ) were tested using a waist belt shaped wireless jumping assessment device (Freejump, Sensorize, Italy). Squat jump test is a variation of the vertical jump test method used to determine leg explosive power. In this test, hands are placed on the waist throughout the test and starting position keep about one second and then subject jumps vertically as high as possible without arm swinging or a downward movement. Subjects flexed their knees until they felt a comfortable starting position where semi-squatting position occurred normally at a knee angle of about 85º (Bosco and Komi, 1979). The subjects maintained their posture at least 2 to 3s, which prevented the prestretching of muscles from any preliminary downward movement before jumping. CMJ, where the muscles were prestretched before shortening in the desired direction, made use of the stretch–shortening cycle. The subjects performed maximum vertical jump with hands kept on the hips, started in an upright standing position following a preliminary downward movement by flexing the knee approximately to the same knee angle as the starting position in SJ during CMJ. To provide standardization during vertical jump tests, the subjects performed the jumps with the hands kept on the hips. The subjects performed 2 maximum vertical jump in starting position and landed on the floor with the legs kept straight for both SJ and CMJ. Each jump attempt was separated with a 1-minute rest period and the best attemps were recorded for statistical assessment.

Isokinetic strength tests

Isokinetic concentric and concentric knee extension and flexion torques were tested at three angular velocities (60, 180, and 300º/s) of dominant leg with a computer controlled isokinetic dynamometer (Humac Norm Testing & Rehabilitation System, USA) at the end of 90s rest period following the jumping tests. Subjects performed 5 maximal efforts with 60s rest intervals after each test at a given angular velocities as recommended by Davies et al (Davies et al., 2000) and the highest value of these efforts was accepted as the peak torque. Subjects performed three maximum efforts before testing at each angular velocity to warm-up. Each test started after 30s rest period at the end of each angular velocity warm-up. The subjects were verbally encouraged during all test process. The calibration of the isokinetic dynamometer was done according to CSMI (2003) before the test sessions. Dynamometer attachments were adjusted to each subject before the tests. The range of motion of the knee joint were adjusted to exactly 0-90º position as described by CSMI (2003) after the subjects placed in the two-position seat of the dynamometer for the knee flexion/extension test. Dynamometer axis of rotation was aligned with using the lateral femoral epicondyle. The calf pad was placed proximal to the lateral malleolus. Each subject was confortably stabilized by straps including thigh, waist, and chest to minimize trunk and thigh movements. Each subject gripped the handles located in each side of the seat throughout the test.

Ratings of perceived exertion

Subjects were asked to evaluate the intensity of the low and high of LB-EMS sessions (30 and 100Hz) and control session (0Hz) on Borg's rating of perceived Exertion (RPE) scale (Borg, 1982) between 6 (very low) and 20 (very high). The same investigator also recorded these evaluations during each session.

Statistical analysis

A two-way analysis of variance (Friedman's ANOVA) with repeated measure was used to compare all three conditions of each isokinetic strength measures and jump performances. If there was a significant difference as a result of variance analysis, Wilcoxon test was used to determine statistical differences between two of the three conditions. Descriptive statistics were applied to identify the chracteristics of the subjects on each conditions, mean scores and standart deviation values were calculated for each participant's three conditions in each isokinetic and jump performances. All data were expressed as mean ±SD that can be seen Table 3. Statistical significance was set to a probability level of $p \leq 0.05$ at the %95 level of confidence. All statistical analyses were run using the Statistical Package for the Social Sciences (IBM SPSS), version 20 for Windows (SPSS Inc., Chicago, IL).

Results

The effects of acute LB-EMS application with multi-joint participation at maximal tolerated comfortable current intensity on jumping performance, perceived exertion and isokinetic strength values are given in the Table 3 and 4.

Jumping performances

As a result of the statistical analysis, a significant improvement in both SJ and CMJ height ($p<0.05$) was obtained after the LB-EMS application. There were significant differences in LB-EMS applications among the control, low and high frequency conditions in SJ ($p<0.05$), CMJ ($p<0.05$) (Table 3). There is a statistically significant different in low- and high-frequency LB-EMS conditions ($p<0.05$) compared to the control condition LB-EMS to control condition in SJ and CMJ (Table 4). There was no significant difference between low frequency and high frequency LB-EMS in CMJ.

Ratings of perceived exertion

The perceived exertion rates significantly ($p<0.001$) increased during LB-EMS application in each of low- and high frequencies compared to control condition LB-EMS frequency (Table 3). Perceived exertion values were significantly higher in the low and high frequency LB-EMS conditions compared to the control condition LB-EMS frequency ($p\leq0.001$) and also high frequency LB-EMS condition compared to low frequency LB-EMS condition ($p<0.05$).

Table 3. Comparisons and descriptive statistics (mean value ± SD) of dominant knee extension/flexion isokinetic torque values (Nm), vertical jump performances (Cm) and rating of perceived exertion values after low, high and control LB-EMS frequency conditions

		Control Frequency (0Hz) (n = 14)	**Low Frequency (30Hz) (n = 14)**	**High Frequency (100Hz) (n = 14)**	**Chi-Square**	**P**
60°/s	**Extension**	175.9±37.0	178.7±42.2	172.2±42.6	2.704	>0.05
	Flexion	120.0±26.0	122.8±44.2	129.0±33.6	1.811	>0.05
180°/s	**Extension**	118.0±19.5	122.5±21.0	120.9±21.8	1.962	>0.05
	Flexion	98.5±14.7	109.5±16.4	108.2±17.7	8.618	<0.05*
300°/s	**Extension**	87.2±13.1	93.0±13.1	92.9±17.0	3.000	>0.05
	Flexion	78.7±10.5	88.7±15.3	87.8±13.5	8.982	<0.05*
	SJ	28.9±3.1	31.3±3.0	31.7±2.9	12.286	<0.05*
	CMJ	32.0±2.7	33.8±3.5	34.0±3.1	11.511	<0.05*
	RPE	6.0±0.0	14.2±1.5	15.9±1.9	27.111	<0.001**

† Nm = Newton meter. Differences between measurements are shown (* $p \leq 0.05$ and ** $p \leq 0.001$). Ex:Extensor, Flex:Flexor

Isokinetic strength performances

It can be seen on the Table 3 that there are statistically significant differences in dominant knee flexion torque values at 180°/s and 300°/s angular velocities ($p<0.05$) related to low, high and control condition LB-EMS frequencies. There are no significant changes in other torque values at all three conditions. Knee flexion torque values are significantly higher in the low and high frequency conditions compared to control condition at 180°/s angular velocity ($p<0.05$) and the low and high frequency conditions compared to control condition at 300°/s angular velocity ($p<0.05$) but not high frequency condition compared to low frequency condition at all torque values (Table 4).

Table 4. Comparisons of dominant knee flexion isokinetic strength, vertical jump performance and ratings of perceived exertion after low, high and control LB-EMS frequency conditions

	Control - Low		**Control - High**		**High - Low**	
	Z-score	**P**	**Z-score**	**P**	**Z-score**	**P**
180°/s Flexion	-2.835	0.006*	-2.199	0.028*	-0.440	0.660
300°/s Flexion	-2.795	0.005*	-2.138	0.033*	-0.175	0.861
SJ	-2.362	0.018*	-3.081	0.002*	-0.535	0.592
CMJ	-2.469	0.014*	-2.439	0.015*	0.258	0.796
RPE	-3.316	0.001**	-3.314	0.001**	-3.108	0.002*

**$p\leq0.001$; *$p\leq0.05$

Note = The Z-scores are from a Wilcoxon two-sample rank-sum test.

Discussion

In this study we have observed that there are acute effects of a single bout of LB-EMS applications with different frequencies (30Hz and 100Hz) on isokinetic strength and jump performance. The results have shown that knee flexion torques at 180 and 300º/s angular velocities and jump performances increased after the 16 seconds of LB-EMS at maximal tolerated intensity compared to control condition (0Hz).

This study was limited to a single-center and subjects were physically active healthy men. EMS was applied for 16 seconds to quadriceps and calf muscles major during static 90° squat exercise. Jumping tests were limited to SJ and CMJ, isokinetic strength was limited to knee flexion/extension torques at 60,180, 300º/s the angular velocities and RPE assessments were tested with the Borg Scale. Future studies on this issue should be organized by considering these limitations.

Present results are in accordance with the findings of Borniquez et al (1993) who have reported increases in muscular strength and jumping performance after the short term of EMS training in volleyball players. In additon, Mafiuletti et al (2002a), Malatesta et al (2003), and Marqueste et al (2010) have reported increases in muscular strength and jump performance after the 4-week EMS training. Marqueste et al (2010) have noted that chronic EMS implementation on accurate muscle group may cause long-term increases in muscular performance and motor unit recruitment. The most obvious change in nervous system functions is the increase in neural drive from supraspinal enters to muscles after EMS resistance training. Vertical jumping control largely based on preprogrammed patterns of muscle contraction. Therefore such a movement control relies heavily on the storage capacity of the central nervous system (Malatesta et al., 2003; Van Zandwijk et al., 2000). Delayed optimization of such templates in the central nervous system can delay vertical jump development (late neural adaptation) after EMS training (Jubeau et al., 2006; Maffiuletti et al., 2002b). However, jump performance and isokinetic strength improvements were obtained immediately after the LB-EMS application in the present study. Findings of this study suggest that the neural mechanisms may play an important role in acute EMS application. Maffiuletti et al (2000) have found that the 4 weeks EMS training increased strength at high concentric velocities (180, 240 and 300º/s) but had no effect at slow concentric velocities (60 and 120º/s) of knee extensors and jumping performance (SJ and CMJ). The present study supports Maffiuletti et al (2000) results. Fast motor units play an important role at high concentric velocities (Thorstensson et al., 1976; Maffiuletti et al., 2000). Motor units are differently activated (Gregory and Bickel, 2005) according to Henneman's size principle during EMS (Henneman, 1965). Recruitment pattern during EMS is nonselective and synchronous (Gregory and Bickel, 2005; Bickel and Gregory, 2011). These findings indicate that EMS training can activate fast motor units more easily than voluntary contraction, and that way EMS can elicit postactivation potentiation (PAP). However voluntary contraction (VC) is more effective than EMS (Enoka, 2002; Xenofondos et al., 2010; Seyri and Maffiuletti, 2011; Anthi et al., 2014).

PAP, an acute neuromuscular performance improvement after the high intensity contractions, could be another explanation for these performance improvements (Hodgson et al., 2005; Sale, 2004). Hodgson et al (2005) have suggested that PAP compensates for the negative effects of fatigue, provides a positive potentiation by increasing motoneuron excitability (i.e. H-Reflex), and it increases contractile protein calcium sensitivity. It is possible that the effects of PAP are more easily elicited using electrical stimulation compared with voluntary muscular actions (Hodgson et al., 2005, Baudry et al., 2008). Baudry and Duchateu (2007) have found similar significant enhancement peak torque and voluntary contractions associated with PAP (Baudry and Duchateu, 2007). Maffiuletti et al (2002b) have suggested that PAP significantly increased (%11.9) after the 4 week EMS training of plantar flexor muscles (75 Hz, 400μs, 16 training sessions) which is supported by the results of the present study.

On the contrary, Boerio et al (2005) haven't found significant difference in PAP immediately after a 13 minutes of EMS bout of plantar flexor muscles (75Hz, 400μs, 30 contractions) or the MVC torque of the plantar flexor muscles significantly decreased. Boerio et al (2005) have described that longer duration of EMS application resulted in fatigue attributable to both central and peripheral factors. Accordingly, EMS application protocol with optimum duration can be effective to elicit PAP. Therefore, it can be concluded that after a single bout of LB-EMS programs at different frequencies in suitable duration can enhance vertical jump height and muscle strength within the acute period in moderately trained men.

The results of the present study have shown significant increase in and 300º/s angular velocities after a squat and counter movement jump heights, and knee flexion torque values at 180º/s single bout of LB-EMS application at low and high frequencies (30Hz and 100Hz) in moderately trained men. These findings support the idea that chronic LB-EMS programs are effective to induce longterm neuromuscular adaptations in explosive activities such as vertical jumps. Current frequencies (30Hz and 100Hz) used in this study could be suggested to be appropriate to induce the mechanisms responsible for our results.

Conclusion

This study has indicated that an acute 16-seconds bout of LB-EMS at 30 and 100 Hz significantly improves jumping performances (SJ & CMJ), knee flexion isokinetic strength at 180 and 300º/s in 30Hz and 100Hz in comparison to the control condition (0Hz). The findings of the present study ilustrate that a single bout of lower body EMS can be effective in acute performance improvement on muscle strength and jumping activities of moderately trained men and higher current frequencies cause higher performance improvements than lower frequencies. These EMS protocol may be incorporated with strength and conditioning training to enchance explosive power for acute adaptations. Exercise and training professionals can use LB-EMS at high frequency to potentiate explosive movements and jumping activities during warm-up session before training or competition in sub-elite athletes. However, the exact mechanisms lying beneath this study still remains uncovered and therefore, further studies need to be eluciated to obtain more clear results on chronic LB-EMS training and using well-trained athletes can be recommended.

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References

Anthi, X., Dimitrios, P., and Christos, K. (2014). On the mechanisms of post-activation potentiation: The contribution of neural factors. *Journal of Physical Education and Sport*, 14(2), 134-137.

Baudry, S., Duchateau, J. (2007). Postactivation potentiation in a human muscle: effect on the load-velocity relation of tetanic and voluntary shortening contractions. *Journal of Applied Physiology*, 103(4), 1318-1325.

Baudry, S., Klass, M., and Duchateau, J. (2008). Postactivation potentiation of short tetanic contractions is differently influenced by stimulation frequency in young and elderly adults. *European journal of applied physiology*, 103(4), 449-459.

Bax, L., Staes, F., and Verhagen, A. (2005). Does neuromuscular electrical stimulation strengthen the quadriceps femoris?. *Sports Medicine*, *35*(3), 191-212.

Bickel, C. S., Gregory, C. M., and Dean, J. C. (2011). Motor unit recruitment during neuromuscular electrical stimulation: a critical appraisal. *European journal of applied physiology*, *111*(10), 2399-2407.

Boerio, D., Jubeau, M., Zory, R., and Maffiuletti, N.A. (2005). Central and peripheral fatigue after electrostimulation-induced resistance exercise. *Medicine and science in sports and exercise*, *37*(6), 973-978.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Med sci sports exerc*, *14*(5), 377-381.

Bosco, C., and Komi, P. V. (1979). Potentiation of the mechanical behavior of the human skeletal muscle through prestretching. *Acta Physiologica Scandinavica*, *106*(4), 467-472.

CSMI., (2003). *Humac®NormTM Testing & Rehabilitation System User's Guide Model 770* [pamphlet]. Stoughton, USA.

Davies, G. J., Heiderscheit, B., & Brinks, K. (2000). Test interpretation.*Isokinetics in human performance*, 3-24.

Borniquez, C., Crivellini, M., Divieti, L., Galli, M., & Mancarella, M. (1993). Electrical Stimulation Of Triceps Surae For Muscular Strength Improvement In Volleyball Players. In *ISBS-Conference Proceedings Archive* (Vol. 1, No. 1).

Enoka, R. M. (2002). Activation order of motor axons in electrically evoked contractions. *Muscle & nerve*, *25*(6), 763-764.

Gregory, C. M., and Bickel, C. S. (2005). Recruitment patterns in human skeletal muscle during electrical stimulation. *Physical therapy*, *85*(4), 358-364.

Henneman, E., Somjen, G., and Carpenter, D. O. (1965). Excitability and inhibitibility of motoneurons of different sizes. *Journal of neurophysiology*,*28*(3), 599-620.

Hennessy, E., Coughlan, G., Caulfield, B., Crowe, L., Perumal, S. D., & McDonnell, T. J. (2010). An investigation into the acute effects of electrical muscle stimulation on cardiopulmonary function in a chronic obstructive pulmonary disease patient-a pilot case study.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activation potentiation.*Sports Medicine*, *35*(7), 585-595.

Holcomb, W. R. (2005). Is Neuromuscular Electrical Stimulation an Effective Alternative to Resistance Training?. *Strength & Conditioning Journal*, *27*(3), 76-79.

Jubeau, M., Zory, R., Gondin, J., Martin, A., & Maffiuletti, N. A. (2006). Late neural adaptations to electrostimulation resistance training of the plantar flexor muscles. *European journal of applied physiology*, *98*(2), 202-211.

Kale, M., Kaçoğlu, C., and Gürol, B., (2014). The effects of electromyostimulation training on neural adaptation and sports performance. Hacettepe Journal of Sport Sciences, *25*(3), 142-158, [In Turkish].

Kemmler, W., Von Stengel, S., Schwarz, J., and Mayhew, J. L. (2012). Effect of whole-body electromyostimulation on energy expenditure during exercise. *The Journal of Strength & Conditioning Research*, *26*(1), 240-245.

Komi. P. (Ed.). (2008). *Olympic Encyclopedia of Sports Medicine: Strength and Power in Sport* (Vol. 2). John Wiley & Sons.

Kramer, J. F., and Mendryk, S. W. (1982). Electrical stimulation as a strength improvement technique: a review. *Journal of Orthopaedic & Sports Physical Therapy*, *4*(2), 91-98.

Maffiuletti, N.A., Dugnani, S., Folz, M., Di Pierno, E., and Mauro, F., (2002a). Effect of combined electrostimulation and plyometric training on vertical jump height. *Med Sci Sports Exerc,* 34(10), 1638-1644.

Maffiuletti, N. A., Pensini, M., and Martin, A. (2002). Activation of human plantar flexor muscles increases after electromyostimulation training. *Journal of Applied Physiology*, *92*(4), 1383-1392.

Maffiuletti, N. A., Cometti, G., Amiridis, I. G., Martin, A., Pousson, M., and Chatard, J. C. (2000). The Effects of Electromyo-stimulation Training and Basketball Practice on Muscle Strength and Jumping Ability. *International journal of sports medicine*, *21*(6), 437-443.

Malatesta, D., Cattaneo, F., Dugnani, S., and Maffiuletti, N. A. (2003). Effects of electromyostimulation training and volleyball practice on jumping ability. *The Journal of Strength & Conditioning Research*, *17*(3), 573-579.

Marqueste, T., Messan, F., Hug, F., Laurin, J., Dousset, E., Grelot, L., and Decherchi, P. (2010). Effect of repetitive biphasic muscle electrostimulation training on vertical jump performances in female volleyball players.*International Journal of Sport and Health Science*, *8*, 50-55.

Porcari, J. P., Mclean, K. P., Foster, C., Kernozek, T., Crenshaw, B., and SWENSON, C. (2002). Effects of electrical muscle stimulation on body composition, muscle strength, and physical appearance. *The Journal of Strength & Conditioning Research*, *16*(2), 165-172.

Robbins, D. W. (2005). Postactıvatıon potentiation and its practical applicability. *The Journal of Strength & Conditioning Research*, *19*(2), 453-458.

Sale, D. (2004). Postactivation potentiation: Role in performance. *British journal of sports medicine*, *38*(4), 386-387.

Seyri, K. M., and Maffiuletti, N. A. (2011). Effect of electromyostimulation training on muscle strength and sports performance. *Strength & Conditioning Journal*, *33*(1), 70-75.

Strauss, G. R., and De Domenica, G. (1986). Torque production in human upper and lower limb muscles with voluntary and electrically stimulated contractions. *Australian Journal of Physiotherapy*, *32*(1), 38-49.

Taifour, A. M., Al Nawaiseh, A., and Khasawneh, A. S. (2013). Isokinetic and isometric strength after electrical stimulation on Judo players. *Journal of Physical Education and Sport*, 13(3), 400-408.

Thorstensson, A., Grimby, G., and Karlsson, J. (1976). Force-velocity relations and fiber composition in human knee extensor muscles. *Journal of applied physiology*, *40*(1), 12-16.

Vanderthommen, M., and Duchateau, J. (2007). Electrical stimulation as a modality to improve performance of the neuromuscular system. *Exercise and sport sciences reviews*, *35*(4), 180-185.

Van Zandwijk, J. P., Bobbert, M. F., Munneke, M., and Pas, P. (2000). Control of maximal and submaximal vertical jumps.*Medicine and science in sports and exercise*, *32*(2), 477-485.

Walmsley, R. P., Letts, G., and Vooys, J. (1984). A comparison of torque generated by knee extension with a maximal voluntary muscle contraction vis-a-vis electrical stimulation. *Journal of Orthopaedic & Sports Physical Therapy*,*6*(1), 10-17.

Xenofondos, A., Laparidis, K., Kyranoudis, A., Galazoulas, C.H., Bassa, E., and Kotzamanidis, C., (2010). Post-activation potentiation: Factors affecting it and the effect on performance. *Journal of Physical Education and Sport*, 28(3), 32-38.

Yanagi, T., Shiba, N., Maeda, T., Iwasa, K., Umezu, Y., Tagawa, Y., ... and Basford, J. R. (2003). Agonist contractions against electrically stimulated antagonists. *Archives of physical medicine and rehabilitation*, *84*(6), 843-848.