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Effects of lower-body electromyostimulation training and detraining on anthropometric parameters and muscular performance

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Abstract

Objective: the aim of this study was to investigate the effects of 6-week lower-body EMS (LB-EMS) training and detraining on anthropometric parameters and muscular performance. **Method**: physically active 38 volunteers (21.5±2.5 years, 175±6.5 cm, 67.7±7.7 kg, BMI: 21.7±1.9 kg/m^2, body fat percentage: 14.4±5.3 %) were randomly divided into LB-EMS group (n: 16) and voluntary group (n: 22). In pre-training, post-training and post-detraining, anthropometric measurements and tests including squat jump (SJ) and countermovement jump (CMJ), 40m sprint, knee isokinetic strength at 60, 180 and 300^{o}.s^{-1} angular velocities, anaerobic power (AP) and anaerobic capacity (AC) were conducted. EG with LB-EMS and VG without LB-EMS participated in the training applied with maximal voluntary isometric contractions (MVIC) between the knee joint angles of 110-120^{o} on a seated leg press machine for a 6-week. Following this period all participants didn't perform any lower-body exercises during 4-week detraining period. **Results**: in SJ, significant differences between the groups (p: 0.043) and within the groups (p: 0.034) were reported after training and detraining. No statistically significant intergroup difference was reported in terms of parameters of anthropometry, CMJ, 40m sprint, isokinetic strength, AP-AC. The results showed that 6-week LB-EMS training and the following 4-week detraining didn't have effect on muscular performance parameters except for SJ. As a result, the 6-week LB-EMS training and the following 4-week detraining didn't cause any change in anthropometric and muscular performance parameters except for SJ height. **Conclusion**: It has concluded that LB-EMS training applied to MVICs isn't more effective than conventional voluntary training in physically active individuals.

Key words: Electrical stimulation, Anthropometry, Athletic performance, Muscle strength, Detraining.

Introduction

Electromyostimulation (EMS) is a muscle activation application with electrical currents on muscle or nerve regions through surface electrodes. It is used for increasing muscular performance in healthy muscles and rehabilitation of muscles which have lost their function (Cardinale & Kazunori, 2010; da Silva et al., 2018; Seyri & Maffiuletti, 2011). It has been known since the 18th century that stimulate artificial contractile activity in neuromuscular system is possible with electrical currents that are applied at a rate which does not cause any pain to the muscle tissue, intramuscular nerve branches or motor points through the skin with electrodes (Bax et al., 2005; Seyri & Maffiuletti, 2011; Vanderthommen & Duchateau, 2007). For the last 20 years, EMS has been used as a method of reducing immobilization-related atrophy with the aim of rehabilitation, preservation of muscle strength after a period of disability and operation and recovering strength losses and it is more effective than physiotherapy applications involving voluntary contraction in these areas (Hauger et al., 2018; Lake, 1992; Snyder et al., 1994). In addition to EMS wide range of clinical use, its popularity has increased as a training method for general strength development to support strength training in sports (Cardinale & Kazunori, 2010; Zatsiorsky & Kraemer, 2006).

The increasing interest in EMS in sports has been due to Yakov Kots stated in a conference at Concordia University in 1977 that high-frequency short-term EMS training could provide high-level athletes with up to 40% strength gains in a short time (Gondin, et al., 2011; Lloyd et al., 1986; Parker et al., 2003; Vanderthommen & Duchateau, 2007; Ward & Shkuratova, 2002). There have been large increases in the EMS studies on healthy individuals over the last few decades, and a wide range of applications and devices have been produced. As a result, EMS has begun to attract attention as a new strength training method for athletes (Zatsiorsky & Kraemer, 2006; Malatesta et al., 2003).

Although there are studies showing that target-muscle-oriented EMS applications have positive effects on neuromuscular parameters in athletes and healthy individuals (Bax et al., 2005; Brocherie et al., 2005; Strojnik, 1998) there are few studies on the effects of EMS training with multi-joint on muscular performance (Berger et al., 2020; Filipovic, et al., 2016; Kemmler et al., 2016; Porcari et al., 2002). There is no study on the effects of LB-EMS, which is applied to the lower body and includes multi-joint or the effects of EMS synchronous with isometric voluntary maximal contractions including lower body bilateral multi-joints on muscular performance. There are also quite a lot of studies in the literature that have different results with different application protocols (Filipovic, et al., 2012; Ludwig et al., 2020; Malatesta et al., 2003; Mathes et al., 2017). Due to these differences, there is no common consensus about training methods of electrical muscle stimulation.

It has been stated that EMS firstly causes a deterioration of nerve muscle conduction, then at the end of the detraining, strength development emerges while conduction returns to normal and this is called delayed adaptation. To our knowledge, there is no study on the effect of LB-EMS application on delayed adaptation and while the majority of studies on the effects of EMS on performance include EMS with bilateral or unilateral single joint. There is no study about the effects of LB-EMS training applied during isometric leg press exercise with bilateral multi-joint on performance. The aim of this study was to investigate the effects of LB-EMS training and detraining on anthropometric parameters and muscular performance. The hypothesis of this study was that 6-week LB-EMS training, and 4-week detraining induces the increases in muscular performance and the changes in anthropometry.

Methods

Subjects

Volunteered 38 Sports Science students (9 females, 29 males) (21.5±2.5 years, 175.5±6 cm, 67.7±7.7 kg, 21.7±1.9 kg/m², fat percentage: 14.4±5.3%), physically active and no experience about EMS, randomly divided two group (EG and VG) in the study. Disorders for an EMS study listed by Stöllberger and Finsterer (2018) were used for exclusion criteria of the study. The study was approved by Eskişehir Osmangazi University, Clinical Research Ethics Committee. Each subject was informed about the study, which was performed in compliance with the Helsinki Declaration, and an informed consent form was signed.

Research procedure

Calf and thigh circumferences, calf and thigh skinfold, body fat percentage (BFP) were measured and SJ, CMJ, 40m sprint, isokinetic knee flexion-extension strength at different angular velocities (concentric/concentric, 60, 180 and 300°.s^{-1}), AP-AC were tested in 3 consecutive days in the weeks of pre-training, post-training, and post-detraining. Before each test, the content of the test was repeated verbally. All subjects participated familiarization process in one week before the pre-tests. As Paillard et al. (2005) and Aldayel et al. (2010) stated that if the subjects participate in first LB-EMS training without adaptation, it might cause anxiety, concern, delayed onset muscle soreness and more pain. Therefore, a LB-EMS training was applied during the familiarization period. After the pre-tests, EG with LB-EMS and VG without LB-EMS participated in the training applied with MVICs between the knee joint angles of 110-120º on a seated leg press machine for 2 non-successive days a week for 6-week. In each training session, the subjects applied a total of 60 MVICs in 3 sets of 20 reps (rest intervals: 5 min between sets, 10 s between reps) on the seated leg press machine at the designated position, which was adapted from the study of Dreibati et al. (2011). The subjects retested in post-training and post-detraining weeks. The study design is shown in Table 1.

Table 1. Study design.

1st Week: Pre-training Tests			
Time	**1st Day**	**2nd Day**	**3rd Day**
08:00 - 10:00	Anthropometric and BFP measurements Jump tests		
15:00 - 16:00	40m sprint test	Isokinetic tests	AP-AC tests
Between 2nd and 7th Weeks: Training Period			
8th Week: Post-training Tests			
Time	**1st Day**	**2nd Day**	**3rd Day**
08:00 - 10:00	Anthropometric and BFP measurements Jump tests		
15:00 - 16:00	40m sprint tests	Isokinetic tests	AP-AC tests
Between 9th and 12th Week: Detraining Period			
13rd Week: Post-detraining Tests			
Time	**1st Day**	**2nd Day**	**3rd Day**
08:00 - 10:00	Anthropometric and BFP measurements Jump tests		
15:00 - 16:00	40m sprint test	Isokinetic tests	AP-AC tests

LB-EMS Training

EG participated in 25-minutes LB-EMS training twice a week at the designated time of the day with at least one day rest interval (Deley et al., 2011; Dreibati et al., 2011) (Figure 1) for 6-week, involved electrical stimulation synchronized with 5-s each for 60 MVICs at the knee joint 110-120º on a seated leg press machine, which was adapted from the protocol of Jubeau et al. (2008). Miha Bodytec EMS device (GmbH, Germany; Figure 2) used for LB-EMS training has a feature of activating the major muscles of the calf, thigh and hip area simultaneously and at different intensities. General warm-up (submaximal isometric and dynamic contractions) was performed for 3-5 min before LB-EMS training and then 3 min rest was given. EMS was applied synchronous with MVICs because of 60% and above of the training intensity more effective to produce to a high level of force during EMS training session (Dreibati et al., 2011).

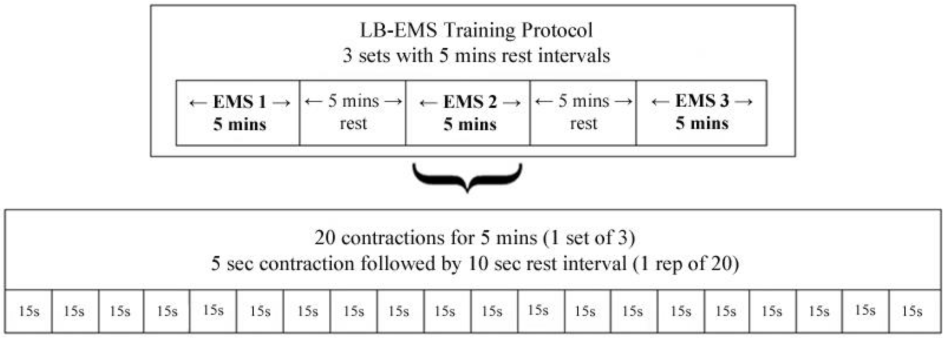

Figure 1. LB-EMS training protocol (adapted from Dreibati et al., 2011).

Figure 2. LB-EMS device.

The features of the electrical stimulations selected for the LB-EMS training protocol are given in Table 2. Since the chronaxie values of motor axons were 200-400µs and for the wide-pulse protocols (300-400µs) to provide stronger contractions, the pulse duration was determined as 400µs in this study. Since the most effective frequency of repetitive stimulation is 50-120Hz, the frequency range was determined as 100Hz. Biphasic rectangular forms were selected as electrical waveforms (Malatesta et al., 2003). Besides, working rate, known as the optimal break period during EMS application was determined as 33%.

Table 2. EMS parameters (Dreibati et al., 2011; Deley et al., 2011).

EMS parameters	
Wave form	Biphasic symmetrical rectangular pulses
Pulse duration	400µs
Pulse frequency	100Hz
Working rate	5 s EMS, 10 s break (33%)
Amplitude	Comfortably maximal tolerated value
Application time	5x3 min= 15min EMS, 2x5min= 10min break, Total= 25dk
Total number of contractions	20x3= 60 contractions

As tolerance to electrical currents is developed over time, the current intensity (CI) is increased at regular intervals at the tolerable comfortable maximal CI perceived by the subjects during the training period (Balogun et al., 1993; Gondin et al., 2011). A 10-cm visual analog scale (VAS) (Figure 3), which is one of the most commonly used scale in perceptual assessment measurements, was used for the detection of nociceptive sensory input caused by EMS application, in order for this CI to be regulated (Bijur et al., 2001; Gould et al., 2001). The fact that when the perceived value in this visual scale is set to 1, it corresponds to the "minimum intensity", when it's set to 10, it corresponds to the "maximum intensity" degree was told to subjects. At the 3rd min of each set, the electrical CI was increased and stopped at the point where the subject perceived the difficulty level of 8-9 (Mcloda & Carmark, 2000). At the end of each EMS training, tolerable comfortable maximal CIs of subjects were recorded and the CI regulation was made accordingly at the next training session.

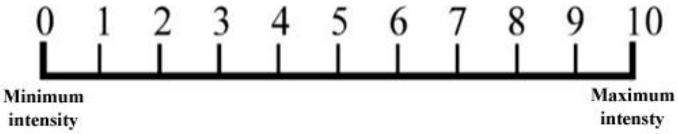

Figure 3. Visual analog scale.

Data Collection

Pre-training, post-training and post-detraining measurements and tests were carried out, considering the chronobiologic effects, by the same researcher between the hours of 08:00-10:00 and 15:00-16:00. Body height was measured the nearest +0.1cm with a fixed wall stadiometer (Holtain Ltd., UK) and body weight was measured the nearest +0.1kg with an electronic scale (Seca, Vogel & Halke, Hamburg) as Lohman et al. (1988) suggested. Calf and thigh skinfold were measured on the right side of the body by using a skinfold caliper (Holtain Ltd., UK) (10 g/mm^2 constant pressure) as Harrison et al. (1988) suggested. Calf and thigh circumferences were taken on the right side of body with an Gullick meter (±1 mm) as

Callaway et al. (1988) suggested. BFP was measured with a BIA analyzer (Tanita MC 180MA, Japan). The means of the measurements, each of which was done twice, were evaluated in the statistical analysis.

Unloaded cycling on a bicycle ergometer (Monark Exercise AB, Sweden) and standard warm-up with various lower-extremity muscle contractions (squat movements, jumps, ballistic exercises, calisthenics) were performed for approximately 15 min before the tests. SJ and CMJ were tested with a wireless inertial measurement device (Freejump, Sensorize, Italy) which was fixed on the body around the waist with an elastic belt. While the jumping tests applied, the hands were on waist, feet were shoulder width apart and eyes looking forward. SJ was exercised by jumping vertical from 90^o fixed squat position and CMJ was exercised while standing on foot, by getting into squat position at 90^o and jumping vertical as soon as possible. The highest jump heights in the 3 trials performed in SJ and CMJ were evaluated statistically. Forty-meter sprint was recorded by customized Precision Timing System (PTS) (MP501, Tümer Elektronik Ltd., Turkey) in an indoor tartan track. Photocells of PTS were adjusted to trochanter height to standardize the cutting point of infrared light. Each subject started the sprint when he is ready on a standing start 1m behind the first photocell. The sprint test was repeated 3 times with 5 min recovery and the best trial was retained for statistical analysis. The isokinetic tests were performed by using a computer-controlled isokinetic dynamometer (Humac Norm Testing & Rehabilitation System, Model TM 770, USA). As Chan and Mafulli (1996) indicated, before each angular velocity test, 3 submaximal repetitions were performed for warm-up and adaptation and then as Davies et al. (2000) indicated, 30 s break was given. A concentric 5 maximal knee flexion/extension torques at the angular velocities of 60°, 180° and 300°.s^{-1} with 1 min breaks were tested. The average peak torque values (Nm) were evaluated statistically. AP-AC test was performed by using bicycle ergometer (Peak Bike, Monark Exercise AB 894E, Sweden) with Wingate anaerobic test which included maximum pedalling in 30 s with the load prepared as 75 g per kilogram of body weight as Inbar, Bar-or O, and Skinner, (1996) indicated. AP-AC and isokinetic strength tests were performed once. Before all the performance tests, the subjects who were encouraged verbally were instructed to perform maximal performance to help them perform maximal effort throughout the tests.

Data Analysis

SPSS 20 software (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. Data are presented as mean and standard deviation (mean ± SD). Whether or not the variables distributed normally was determined by Kolmogorov Smirnov test and logarithmic transformation was applied to the variables that did not show normal distribution so that they could provide normal distribution consistency. Mann-Whitney U Test was used to detect whether there was any difference between the pre-test values of EG and VG or not. While two-way variance analysis was used for repeated measurements, the homogeneity of the variance was analyzed by Box-M test. A two-way ANOVA test with one-way repeated measures was used to evaluate the main effects of training and to make group and inter-group comparison. The Post-hoc LSD test was used to determine if there was a significant difference in ANOVA test results. A test for the equality of the correlations between all the possible combinations of assumptions of ANOVA with repeated measurements (equality of covariances) and sphericity test were performed. Partial Eta Squared was used for effect size.

Results

Pre-training, post-training, and post-detraining results of anthropometric, jump, sprint, AP, AC, isokinetic strength parameters based on 6-week LB-EMS training and the following 4-week-detraning are shown in Tables 3, 4 and 5.

Table 3. Comparisons of pre-training, post-training and post-detraining of the anthropometry and BFP parameters.

Anthropometry and BFP Parameters		EG (n=16)	VG (n=22)	p	ETA
Calf Circumference (cm)	Pre-training	36.2±1.7	35.8±1.8	0.277	0.710
	p	0.048†			
	ETA	0.156			
Thigh Circumference (cm)	Pre-training	53.7±3.7	54.0±3.4	0.280	0.700
	p	0.450			
	ETA	0.045			
Calf Skinfold (mm)	Pre-training	9.6±5.5	8.4±3.5	0.053	0.154
	p	0.234			
	ETA	0.080			
Thigh Skinfold (mm)	Pre-training	15.7±8.7	13.3±6.5	0.565	0.006
	P	0.937			
	ETA	0.029			
BFP (%)	Pre-training	14.3±6.1	14.5±4.6	0.407	0.710
	P	0.486			
	ETA	0.156			

†p<0.05

Calf and thigh circumference, calf and thigh skinfold and BFP measurement results are shown in Table 3. While there was a significant increase in the calf circumference in the EG (P<0.05), there was no significant difference in VG. There were no statistically significant differences between- and within-groups in terms of the thigh circumference, calf and thigh skinfold and BFP values.

Table 4. Comparisons of pre-training, post-training and post-detraining of the performance parameters.

Performance Parameters		EG (n=16)	VG (n=22)	p	ETA
SJ (cm)	Pre-training	30.4±5.5	31.7±6.0	0.043†	0.092
	p	0.034†			
	ETA	0.100			
CMJ (cm)	Pre-training	34.5±6.7	35.4±6.7	0.369	0.032
	p	0.347			
	ETA	0.038			
40m sprint (s)	Pre-training	5.79±0.60	5.72±0.55	0.439	0.018
	p	0.003†			
	ETA	0.133			
AP (W.kg^{-1})	Pre-training	12.3±2.0	12.0±1.3	0.992	0.00
	p	0.070			
	ETA	0.141			
AC (W.kg^{-1})	Pre-training	6.9±1.2	6.8±0.8	0.064	0.145
	p	0.368			
	ETA	0.056			

†$p<0.05$

As seen in Table 4, there was a statistically significant difference in both EG and VG in SJ ($p<0.05$). In terms of SJ, there was an increase in the post-training and post-detraining in EG, while in VG there is an increase in the post-training and decrease in the post-detraining. According to these findings, there is a statistically significant increase in SJ height because of the training. It is seen that the detraining had a statistically insignificant effect only on EG. In terms of CMJ, there are no significant differences in intra-group and inter-group. EG's and VG's 40m sprint performance intra-group post-test results are better than the pre-test results ($p<0.05$). At the post-training, there is a no-significant decrease in the 40m sprint performances of both groups. There is no statistically significant inter-group and intra-group difference in AP-AC. Non-statistical small increases occurred in AP post-test results of VG and EG in comparison with the pre-test results. There was not any decrease in these results in the post-detraining. In addition, in terms of AC, there was only a statistically insignificant decrease in EG in the post-training.

Table 5. Comparisons of pre-training, post-training and post-detraining of isokinetic knee strength parameters.

Isokinetic Parameters			Right Knee Peak Torque Values (Nm)				Left Knee Peak Torque Values (Nm)			
Angular Velocity			EG (n=16)	VG (n=22)	p	ETA	EG (n=16)	VG (n=22)	P	ETA
Flexion	60°.s^{-1}	Pre-training	134±34	132±29	0.286	0.034	130±35	130±28	0.968	0.000
		p	0.006†				0.103			
		ETA	0.152				0.064			
	180°.s^{-1}	Pre-training	104±24	100±22	0.060	0.065	103±25	100±22	0.978	0.000
		p	0.491				0.404			
		ETA	0.021				0.023			
	300°.s^{-1}	Pre-training	86±20	84±20	0.237	0.039	86±20	86±19	0.227	0.041
		p	0.576				0.461			
		ETA	0.014				0.019			
Extension	60°.s^{-1}	Pre-training	186±51	179±39	0.346	0.039	183±51	178±36	0.479	0.019
		p	0.018†				0.009†			
		ETA	0.138				0.135			
	180°.s^{-1}	Pre-training	129±33	123±27	0.284	0.038	125±33	119±25	0.589	0.013
		p	0.299				0.186			
		ETA	0.037				0.047			
	300°.s^{-1}	Pre-training	96±26	92±21	0.130	0.022	93±27	89±19	0.628	0.026
		p	0.427				0.386			
		ETA	0.001				0.053			

†p<0.05

As seen in Table 5, there are no inter-group differences in isokinetic flexion and extension peak torques of right knee at angular velocity of 60°.s^{-1} except for EG ($p<0.05$). There are no inter-group and intra-group significant differences in isokinetic flexion peak torques of left knee at the angular velocity of 60°.s^{-1}. As for extension peak torque values, while there is no inter-group difference in terms of intra-group, there is a statistically significant decrease in EG ($p<0.05$). There are no inter-group and intra-group significant differences in isokinetic flexion and extension peak torques of right and left knees at angular velocity of 180°.s^{-1} and 300°.s^{-1}.

Discussion and conclusions

The aim of this study was to investigate the effects of the LB-EMS training, synchronous with MVICs, twice a week for 6-week and the following 4-week detraining period on anthropometric parameters and muscular performance parameters. In this part, the findings of the study about anthropometry, jump, 40m sprint, isokinetic strength, AP and AC parameters were discussed separately.

Anthropometric Parameters

According to the results, there was a significant difference in intra-group while there was no significant difference in inter-group in calf circumference. As for thigh circumference, calf and thigh skinfold and BFP, there were no significant differences according to the intra-group and inter-group results. Besides there were not any differences in the anthropometric parameters and BFP measurements after the training and detraining period compared to voluntary exercise group. Martin et al. (1994) stated that there was no change in *triceps surae* cross-sectional area after the EMS training (4-week, 3 times a week) compared to the control group of physical education students. Similarly, Singer' (1986) showed that there was not difference in *Quadriceps* cross-sectional area after the 4-week EMS training (15 min per day) in the individuals who have weak *Quadriceps* after a knee injury. In contrast to these studies, Gondin et al. (2011) found that there was 12% cross-sectional area increase in Type-I muscle fibers and 23% cross-sectional area increase in Type-IIa muscle fibers after 8-week EMS training. This finding indicated that muscle hypertrophy may develop depending on the participants' profile as a result of a longer-term EMS training. In the 5-week EMS study of Russ et al. (2012) it was revealed that there was a significant increase in the cross-sectional area (3%). These results show that it is possible to achieve different hypertrophic effects with different EMS protocols. Porcari et al., (2002) revealed that in 27 healthy high school students, there was no statistical difference in any of the comparison results of EMS (8-week, 3 days a week) in terms of body weight, BFP, circumference, skinfold and physical appearance and they also stated that EMS didn't have any effect on body composition and circumferences in healthy subjects. Kemmler et al. (2016) compared the full-body EMS and high intensity interval resistance training (HIIT) on 57 people (age: 30-50 years) and that there was a significant decrease in the BFP in comparison with the pre-test results but there was no inter-group difference. Accordingly, they explained that EMS training was not more effective than HIIT training and they had similar effects. Porcari et al. (2005) stated that EMS training (8-week, 5 days a week) on 40 subjects (age: 25-50 year, BMI: 18-30 kg/m^2) is the reason for 3.5cm decrease around the waist in EMS group. As in this study, the age and BMI range of the participants' profile reveal the importance of standardization of EMS training. As a result, it can be said that applied EMS training, subject profile and research design will cause differences in results.

Jump Parameters

In terms of CMJ, there was no statistically significant post-training difference in the EG and VG. It was seen that there was no statistical post-detraining difference in CMJ of VG. As for SJ, after LB-EMS training, it was observed that there was an inter-group and intra-group significant increase (1-2 cm) and this increase was preserved by a small amount at the post-detraining in EG. Herrero et al. (2010) stated that in their study EMS training superimposed with 4-week weight exercises and 2-week detraining on sports science students caused no difference after training and detraining between all groups in SJ, CMJ. According to these results LB-EMS applied on dynamic voluntary contractions at slow angular velocity or isometric contractions, as in this study, does not have any effect on jump performance. Malatesta et al. (2003) found that EMS training (4-week, 3 days a week) included in pre-season volleyball training period did not have any significant effect on male volleyball players in SJ and CMJ. They observed a 5-6% increase in SJ and CMJ after the 10-day routine volleyball training following this EMS training. These findings highlight the delayed adaptation effect of EMS and emphasize the need for EMS to be supported by voluntary dynamic training due to its neural effects. However, our results were different from this study about delayed adaptation aspect. The fact that LB-EMS superimposed with isometric exercise at 110-120^0 knee angle might be the cause of small increases in SJ. In addition, the fact that there was no statistically significant difference in CMJ might have derived from those plyometric exercises which were not combined to the training or detraining period. Deley et al. (2011) investigated the effects of 6-week EMS training combined with the gymnastic training on muscle strength and jump performances. The results showed that statistically significant increase in reaction time, SJ and specific jump heights. These findings support that the effects of EMS on jump might be more distinctive when combined with sports-specific movements. Alberti and Ragazzi (2007) compared the effects of maximum voluntary isometric contraction and EMS on jump and indicated that there was a statistically significant increase in SJ (10%) and CMJ (8%) of EMS group compared to the control group in the results of 1st and the 3rd weeks following the EMS training (5-week, 3 days a week). This study showed that there was an increase in SJ and CMJ although it was conducted on active individuals. Reasons of that might have been that the frequency of training was 3 days a week. Although it was stated that EMS applied 3 times a week provided more strength development than EMS applied twice a week (Parker et al., 2003) there are also studies indicating that EMS training, applied twice a week and combined with football training, increased maximal strength, sprint, jump, and kick performances (Filipovic et al., 2016). If we overview the results in the literature, it can be concluded that the adaptations that occur in performance due to EMS training are affected by many different factors such as individual characteristics, training periodization and application method. Accordingly, it would not be wrong to say that the implementation method of EMS training in this study was insufficient in terms of elastic power development compared with voluntary training.

40m Sprint Performance

No statistically significant difference was observed between the groups in the 40m sprint performance at the end of the LB-EMS training. After 4-week detraining in intra-group and inter-group, statistically significant increases were observed. Accordingly, it can be concluded that this LB-EMS training and detraining are like voluntary exercises in sprint performance. Wolf et al. (1986) revealed that there was an improvement in 23m sprint performance after EMS training applied to *Quadriceps*. According to the current study with similar results, it can be said that LB-EMS training is not more effective than voluntary exercises, and it is not enough to cause delayed adaptation in sprint performance after detraining. However, there are different results in the literature. Maffiuletti et al. (2009) revealed that there was a decrease (23.3%) in the 2x10m sprint duration in the tests conducted 3-week after the EMS training (6 EMS training in 3-week) compared to the pre-test in tennis players. According to this result, although there is a reference to the delayed adaptation effect of EMS in sprint performance, the lack of control group in this study weakens the idea that the result is caused by EMS. Its difference from the current study might derive from the fact that the EMS training in elite athletes have more effective results compared to untrained subjects, as Filipovic et al. (2012) stated. Brocherie et al. (2005) investigated the effects of isometric EMS training applied on *Quadriceps* 3 times a week for 3-week on elite ice hockey players and observed improvement (4.8%) in 10m skate sprint time. According to these results, it can be concluded that the EMS applied to the main muscles involved in the movement may be effective in sports-specific performances of elite athletes. Thus, the fact that the participants in this current study do not have a specific sports events might be the reason for not having significant improvements in their performance. Herrero et al. (2006) investigated that the delayed effects of 4-week EMS training (4 training a week) compared to EMS combined with the plyometric training. Following the two-week detraining, 20m sprint times increased in EMS group (2.4%) but decreased in combined group (2.3%). According to these results they reported improvement in sprint duration in EMS combined with plyometric and plyometric only in physically active males. It was stated that EMS training applied by itself had no effect on sprint performance. This shows that the EMS training applied to physically active males in combination with voluntary exercises is more effective than EMS training only. However, when evaluating the results, the training load in the combined group might be higher compared to the other groups and the number of EMS training per week should be taken into consideration. According to these results, it would be saying that it’s possible to achieve different results with different EMS training protocols and different training periods.

Isokinetic Knee Strength Parameters

In this study, no statistically significant inter-group differences in pre-training, post-training and post-detraining bilateral knee extension and flexion peak torque values at 60, 180 and 300°.s-1 angular velocities were observed. However, significant decreases were observed in right knee flexion torque, right and left knee extension peak torques at 60°.s^{-1} angular velocity in intra-group. Maffiuletti et al. (2000) stated that isometric EMS training applied to *Quadriceps* on male basketball players 3 times a week in addition to the basketball training 5 times a day for 4-week increased 29% at 120°.s^{-1}, % 37 at 60°.s^{-1}, 36% at 360°.s^{-1}, 36% at 300°.s^{-1}, 30% at 240°.s^{-1}, 32% at 180°.s^{-1} but had no effect at 60 and 120°.s^{-1} in EMS group. As for isometric strength, there was a statistically significant increase only at 55 and 65°.s^{-1} which were close to the training angle. Isokinetic and isometric strength results remained constant after 4-week basketball training following the EMS training. Although these are different from the present study results, they associate with the fact that EMS training combined with dynamic exercises in elite athletes will provide more effective results. In Avila et al. (2008) study, healthy individuals applied concentric isokinetic training (3 sets, 10 reps) to both knee extensor muscles at 30°.s^{-1} angular velocity 2 days a week for 4-week while isokinetic training synchronized with EMS was applied to one leg. Although the peak torque values of both legs increased, no significant difference was found between the legs. According to these results, it was stated that EMS and isokinetic concentric voluntary strength training did not provide strength gain and voluntary strength training was more effective in healthy individuals in terms of neuromuscular function. According to the results of the current study, it can be said that LB-EMS is not more effective than voluntary training for leg strength (Kale & Gurol, 2019). As Sanchez et al. (2005) stated, there is a common view that the EMS applied synchronously with voluntary contractions in healthy individuals does not activate motor unit more than those activated during voluntary contractions. Although there is an increase in voluntary strength with EMS training, this is not more than voluntary contractions.

AP and AC Parameters

In this study, the focus is on the lower body muscles which have a large portion of producing explosive type of AP such as jump and sprint. There were no statistically significant AP and AC differences in pre-training, post-training and post-detraining tests. There were statistically insignificant similar post-training increases in both groups in AG. Thus, it can be said that there is no difference between this EMS training and voluntary training. Although there was not a statistically significant AC difference, it was observed in the post-training that there was a slight decrease in EG and a very small increase in VG compared to the initial values. Post-detraining AC got close to the pre-test results with the decrease in EG. Although the post-training test results showed that there was a slight increase in both groups, AP was observed higher in post-detraining test values than its pre-test values and it maintained its post-test values. Mathes et al. (2017) reported that AP and AC showed a statistically significant increase in both the control group and the superimposed EMS group separately after the superimposed EMS training program (14 training sessions) with 4-week cycling exercise but there was no significant difference between the groups. These results that similar with the present study that the EMS training superimposed with the dynamic cycling exercise was not more effective than the dynamic bicycle exercise without EMS in AP and AC. Herrero et al. (2010) founded that superimposed EMS with 4-week weight training and 2-week detraining have no effects in 20m sprint and jump performances of the weight training group and the control group. In the current study, it is concluded that EMS has a similar effect with voluntary exercises in AP and AC. To increase AP with superimposed EMS, EMS training should be made more effectively by supporting it with auxiliary and specific studies such as plyometric jump.

There are several factors affecting the results of EMS applications. Some of these factors are EMS current parameters such as frequency, pulse duration, pulse width, increase and decrease time, current type, waveform, intensity, interval between pulses as well as the application of EMS on voluntary contraction or passive muscle, joint angle on which isometric application is applied, its application on concentric, isometric or eccentric contraction as a voluntary contraction, the form, size, material of the electrodes, percutaneous, transcutaneous, transcranial or interferential applications, chronic or acute application, number of contractions, number of weekly applications, delayed adaptation effect after chronic application, participant’s profiles (physically active or inactive, elite or sub-elite athletes, age groups), multiple or single joint movement, current applied on the muscle belly or on nerve region. There are many factors complicating the possibility of a consensus in practice. Therefore, researchers or coaches who wants to conduct an EMS study should consider all these the factors. Although the modulation of EMS parameters increases the effectiveness of this technique, researchers have a common opinion that there are significant individual differences in response to EMS and that the optimization is related to some internal anatomical and neuromuscular characteristics of individuals rather than the stimulation parameters applied to them. Similarly, the effectiveness of EMS depends on some internal anatomical features such as motor nerve dendrites, morphological structure of the axon dendrites within the muscle, rather than externally controlled factors (current parameters, electrode size, etc.). This case corresponds to the idea that EMS success is determined partially by uncontrollable factors (Cardinale & Kazunori, 2010; Malatesta et al., 2003; Seyri & Maffiuletti, 2011). There are some evidences in the literature that it’s possible to achieve strength gains in a healthy muscle and increases in functional performance with EMS. Besides based on the literature it can be said that EMS doesn’t support whole-body muscular development like voluntary activities, it doesn’t provide inter-muscular coordination, it provides limited development in body composition and voluntary isometric muscle strength, isometric muscle contractions are specific to angle in the EMS, its extreme application might be detrimental effect on motor coordination and EMS with multi-joint is not advantageous compared with voluntary training in terms of time.

In conclusion, LB-EMS study design, applied synchronously with MVIC involving multi-joint, was not more effective in performance increase than voluntary isometric contractions. The basic theory of EMS is that it activates fast-twitch muscle fibers and slow-twitch muscle fibers, whose voluntary activations are more difficult, with synchronous motor unit participation and thus it activates fast-twitch motor units. However, LB-EMS training applied twice a week for 6-week and the following 4-week detraining had a significant effect in SJ compared with voluntary contraction training, but it is not more effective than voluntary contraction training in terms of BFP, calf and thigh circumferences and skinfold, sprint, CMJ, isokinetic knee strength, AP and AC. It is concluded that LB-EMS training applied singly to physically active and healthy individuals is not more effective than conventional voluntary training and that it should be supported with combined studies.

EMS training modifications involving superimposed or combined applications with voluntary exercises to different parts of the body, different age groups and athletes with different performance levels may cause different results. Also, this LB-EMS training can be applied with different training frequency, intensity, and durations. The EMS, synchronized with the MVICs, can be applied in a program in which it is applied similarly in synchronous with the designated percentage of maximal voluntary contraction or where this percentage is increased gradually during the training period. Similar EMS and contraction protocol can be applied to hip and knee extensors and plantar flexors during maximal isometric leg push, dynamic squat.

Conflicts of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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