한국전문물리치료학회지 2019년 26권 4호 42-52 ISSN (Print) 1225-8962, ISSN (Online) 2287-982X
Phys Ther Korea 2019;26(4):42-52 https://doi.org/10.12674/ptk.2019.26.4.042

Effects of Whole Body Electromyostimulation on Muscle Activity and Muscle Thickness of Rectus Femoris, and Muscle Thickness of Abdominis Muscle in Healthy Adults

Keun-hyo Lee[1], MSc, PT, Se-jin Park[2], PhD, Seung-chul Chon[3], PhD, PT
[1]Dept. of Rehabilitation Medicine, Konyang University Hospital
[2]Center for Medical Metrology, Korea Research Institute of Standards and Science
[3]Dept. of Physical Therapy, College of Medical Science, Konyang University

Abstract

Background: Whole body-electromyostimulation (WB-EMS) is widely used for the rehabilitation and recovery of patients with various neuromusculoskeletal disorders.

Objects: To objectively measure changes in lower extremity and abdominal muscles after sit-to-stand dynamic movement training using WB-EMS.

Methods: A total of 46 healthy adults (23 experimental and 23 control subjects) performed sit-to-stand exercise; the experimental group with WB-EMS, and the control group without WB-EMS. The muscle activity of the lower extremity, and the muscle thickness of the lower extremity and abdominal muscles were measured before and after the intervention.

Results: In terms of electromyographic activity, there was a significant interaction effect for the rectus femoris (RF) muscle ($F=30.212$, $p=.000$). With regards to ultrasonographic imaging, the muscle thickness of the RF muscle had a significant interaction effect at the muscle contraction ratio ($F=8.071$, $p=.007$). The deep abdominal muscles, such as the transverse abdominal (TrA) and internal oblique (IO) muscles, also showed significant interaction effects at the muscle contraction ratio ($F=5.474$, $p=.024$, $F=24.151$, $p=.000$, respectively).

Conclusion: These findings suggest that WB-EMS may help to improve the muscular activity of the RF muscle, and the muscle thickness of the RF muscle and deep muscles such as the TrA and IO muscles.

Key Words: Abdominal muscle; Muscular activity; Rectus femoris muscle; Whole body electromyostimulation.

Introduction

Electromyostimulation (EMS) is used in the physical therapy field as a method to rehabilitate muscles after an injury or surgery. Indeed, it has been commonly used to strengthen the extremities of patients who have had orthopedic surgery. The use of EMS can also prevent injuries, especially for individuals who are susceptible to injuries of the lower back, knees, shoulders, and muscles. It has been reported that EMS represents a new form of therapy that increases efficiency and universality by combining the medical device which induces muscle contraction by providing electrical stimulation to clothes (Kemmler and von Stengel, 2013).

Initial EMS studies generally reported on effects resulting from the local application of EMS to individual muscles (Porcari et al, 2002). With further technical advances, only recently has a targeted vest system been developed for EMS that can be applied

Corresponding author: Seung-chul Chon keyjune@konyang.ac.kr
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2017R1D1A3B03031876).

to multiple muscle groups simultaneously; this is known as whole body (WB)-EMS. WB-EMS involves the use of a wearable device that activates muscles through electrical stimulation and can be applied to subjects for muscle strength enhancement, body correction, and diet through various frequencies and waveforms. These wearable WB-EMS devices are being developed in designs and forms that.

Recently, WB-EMS has overcome inconveniences from past systems with advances in functions. In addition, the wire connecting the electrode to the EMS system has been changed to a wireless sensor via Bluetooth technology. This wireless WB-EMS system provides rehabilitation services quickly and easily to a variety of patients (Kemmler et al 2016; von Stengel et al 2015). Furthemore, Filipovic et al (2012) reported that WB-EMS was capable of increasing both muscle strength and mass in athletes; this was later substantiated a positive change to improve muscle strengthening in elderly, sedentary persons and patients with chronic heart failure (Fritzsche et al, 2010; Kemmler et al, 2010; Kemmler and von Stengel, 2013; Kemmler et al, 2014; van Buuren et al, 2013; van Buuren et al, 2014).

Electrophysiologically, electrical stimulation was first used to prevent muscle atrophy by causing involuntary contractions of the muscles resulting in the recruitment of fast-twitch fibers (Lexell et al, 1988). High frequency stimulation above 70 ㎐ can further stimulate deep muscles by activating small motor neurons, and low frequency stimulation can induce muscle contraction of surface muscles by activating large motor neurons (Doucet et al, 2012). Electrical stimulation resulting in muscle contraction has the advantage of enabling efficient exercise performance because it can activate fast-twitch fibers with less effort (Gregory and Bickel, 2005). In addition, these electrical stimulation methods mediate their various effects by controlling the waveform, frequency, intensity, and on-off ratio for the main purpose of muscle strengthening and muscle re-training (Doucet et al, 2012; Maffiuletti et al, 2014).

Specifically, an electric pad of the WB-EMS, located on the inner side of the vest, activates the functional performance of the body; this electric pad transmits a current to the muscle in contact with the skin, and subsequently induces muscle contraction (Maffiuletti et al, 2000). Such an electrical stimulus has an advantage in that the electrical stimulus can be continuously provided when performing dynamic movement as well as in a static state. In addition, it has been reported that it is possible to improve efficiency by providing electric stimulation in addition to active muscle contraction as well as passive muscle contraction (Lieber et al, 1996). Pichon et al (1995) reported that EMS was effective not only in isometric contraction, but also in isotonic contraction, as well as reporting an overall improvement in muscle strength in training using EMS.

However, while some studies have examined the efficacy of WB-EMS, very few studies have quantitatively measured the effects of WB-EMS training combined with dynamic movement. In particular, there are few studies that use objective instruments, such as surface electromyography (EMG) for measuring the muscle activity of superficial muscles, and ultrasonographic (US) imaging for measuring the muscle thickness of deep muscles. Therefore, this study aimed to objectively investigate the changes in abdominal muscles and lower extremity muscles by using WB-EMS for dynamic motions such as sit-to-stand exercise using surface EMG and US.

Methods

Subjects

In total, 46 healthy adults were randomly assigned to the experimental group, comprising 23 subjects who were prescribed sit-to-stand with WB-EMS, or the control group, consisting of 23 subjects who were prescribed sit-to-stand without WB-EMS (Figure 1). Informed consent was obtained from all the subjects, and this study was approved by the

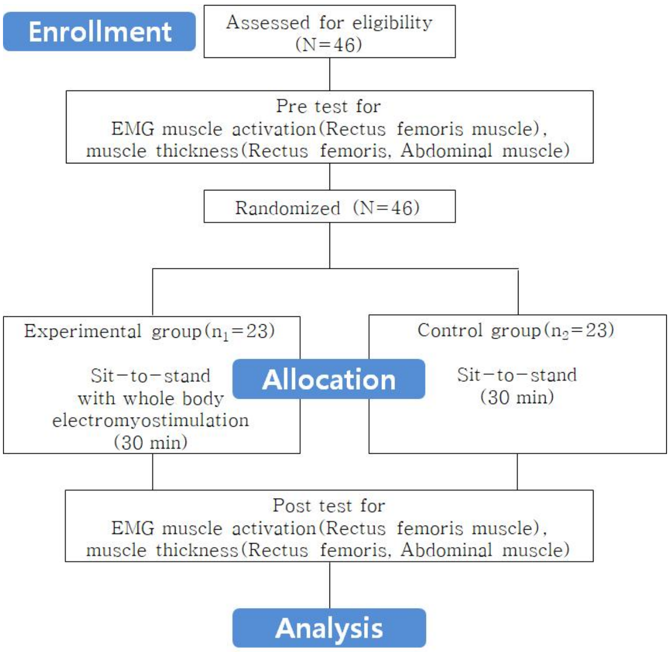

Figure 1. Study design.

university ethics and institutional review board (approval number: KYU-2019-288-01). The study subjects were free from any known medical problems, and the inclusion criteria were as follows: 1) No history of neuromuscular pathology problems, 2) no abnormal hip, knee, or ankle joint problems, 3) no pain of lower extremity, 4) no orthopedic disease, and 5) the ability to perform sit-to-stand exercise and comprehend instructions.

The target sample size was 46 subjects. This number was investigated to yield a power of 85% and an alpha of .05 to detect large differences in effect size between the experimental and control groups. Randomization was carried out using sealed envelopes, and the sealed letters for the experimental group (WB-EMS with sit-to-stand exercise) and the control group (only sit-to-stand exercise) were arranged by the investigator. The investigator prepared group allocation on a sheet of paper and gave it to subjects in a blinded manner. Subjects were allocated before the initial assessment, and all of them participated in the measurements. The physiotherapist who performed the assessment was also blinded to the group allocation.

Intervention

WB-EMS (Active functional wear, Wave-E, Peschiera del Garda, Italy) was performed after 30 minutes of exercise each day, 3 days before intervention by two skilled measurers (Figure 2). The WB-EMS provided 30 minutes feedback for adaptation to electrical stimulation and precise sit-to-stand movement prior to wearing the WB-EMS. The intensity of the EMS was consistently applied to 70% of the pain threshold, the frequency ranged from 2 to

Table 1. General characteristics of subjects (N=46)

Variables	Experimental group (n_1=23)	Control group (n_2=23)	t-value	p-value
Age (year)	21.1±2.2[a]	21.3±1.7	.092	.763
Height (㎝)	165.6±17.5	167.8±9.1	1.776	.190
Weight (㎏)	57.7±9.2	61.4±10.8	.185	.669
BMI[b] (㎏/㎡)	21.1±2.9	21.9±2.9	.073	.788

[a]mean±standard deviation, [b]body mass index.

Figure 2. WB-EMS (whole body-electromyostimulation).

200 Hz, and the pulse amplitude range from 50 to 400 μs to allow for comprehensive and individual adjustments during the study. The training intensity and volume were increased according to the overload principle. EMS training was carried out in accordance with published studies that used the same EMS system for healthy adults. Each of the subjects underwent a test run for familiarization before the study began.

WB-EMS was provided to the rectus femoris muscle and abdominal muscles during the sit-to-stand procedure. For correct sit-to-stand procedure, a straight rod was attached to the back of the subject, both arms were crossed over the front of the chest, the subjects stood comfortably with their feet placed shoulder width apart on the floor, and the gym ball was positioned for maintaining a constant space of both the knee joints, while bending to the instructed knee joint 90˚. The examiner confirmed that the performance was representative of the exact sit-to-stand procedure. In the control group not wearing the WB-EMS, sit-to-stand movements were performed under the same conditions. The WB-EMS program was designed to progress same speed to a sit-to-stand 90˚ of knee flexion, and a metronome was used to measure the sitting speed. Each WB-EMS protocol involved four elements: (1) eccentric contraction of the knee joint from 180˚ to 90˚ for 3 seconds, (2) isometric contraction for 2 seconds to maintain the knee joint at 90˚, (3) concentric contraction of the knee joint from 90˚ to 180˚ for 3 seconds, (4) relaxation for 2 seconds in the standing position holding the knee joint at full extension of 180˚. A total of 3 sets, 15 times per set, were performed. Additionally, a 10 minute warm-up and a 10 minute cool-down comprising passive range of motion exercises were included before and after the EMS program, respectively, and the subjects were instructed to rest for 1 minute between each of the four elements of the EMS protocol. Overall, the EMS protocol took approximately 30 minutes to complete (Figure 3). One licensed physical therapist (5 years of experience) performed the intervention, and a single experienced therapist was employed to ensure standardization of the intervention so as to strictly

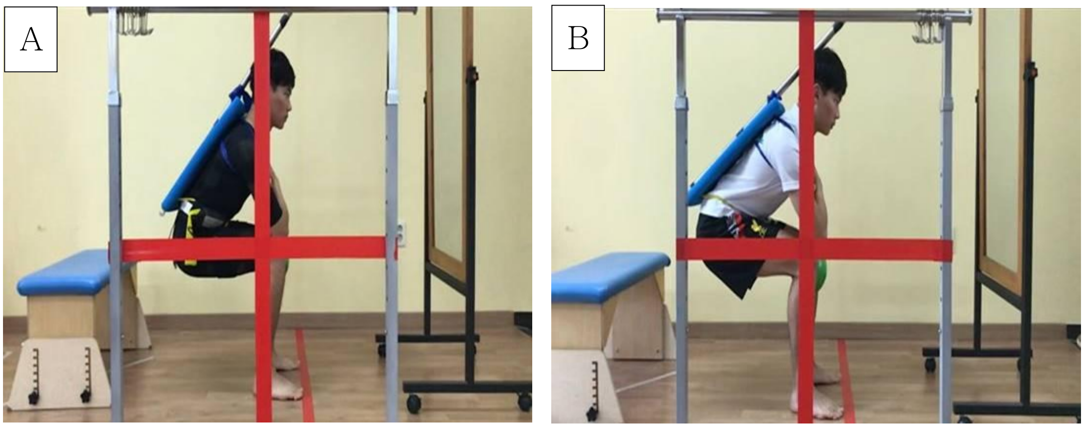

Figure 3. Sit-to-stand exercise (A: Experimental group, B: Control group).

adhere to the treatment protocol described above.

Surface electromyographic recording and data processing

Surface EMG was used to record the amplitudes of the contractions of the rectus femoris (RF) muscle. This measurement was collected for the experimental and control groups in order to determine the activation of this muscle during sit-to-stand. In order to reduce impedance, the skin of each subject was shaved and an electrode gel was applied. A pair of active electrodes (inter-electrode distance of 2 ㎝) was placed in parallel over the muscle bellies to be tested. Tape and elastic straps were used to eliminate cable movement artifacts and to fix the electrode patches onto the skin.

The Myo-Research software (TeleMyo 2400T DTS, Noraxon Inc., Scottsdale, USA) was used to acquire the EMG signals at a sampling frequency of 1024 ㎐, which were processed with a bandpass of 20~450 ㎐ and a 60 ㎐ notch filter. The root mean square (RMS) EMG amplitude for these muscles was calculated using the average time during the sit-to-stand exercise, while the sequential activations of the RF muscle activity were displayed on a computer monitor. Electrode patches with a diameter of 1 ㎝ were placed on the RF muscle at standardized sites, as described by Gilleard et al (1998). To normalize the EMG signals recorded for the RF muscle, the RMS of 5 seconds maximal voluntary isometric contraction (MVIC) was calculated for the RF muscle at the manual muscle testing positions, as recommended by Kendall et al (2005); all of the EMG data were averaged over three repetitions of each measurement. The EMG signals collected were then expressed as a percentage of the calculated RMS of the MVIC (%MVIC).

Ultrasonographic imaging recording and data processing

The US imaging instrument (MicrUs EXT-1H, TELEMED, Vilnius, Lithuania) was used to assess the muscle thickness of the RF and abdominal muscle before and after the intervention. The RF and abdominal muscles, including the external oblique (EO), internal oblique (IO), and transverse abdominal (TrA) muscles, were obtained on the dominant side during the ball was kicked. The RF muscle was respectively measured in the state of maximum isometric contraction of the muscle and in the resting state with the knee joint extended. The rest state of the RF muscle was measured with a pressure biofeedback unit (Chattanooga Stabilizer Pressure Biofeedback, Chattanooga/DJO Global Inc., Guildford Surrey, UK) beneath the knee joint, and the pressure was maintained at 70 ㎜Hg. The ultrasound frequency was set at 10 ㎐ and the position of the transducer head was measured at 15 ㎝ upwards from the center of the patella.

The resting thickness of the abdominal muscle was measured at the end of the tidal volume expiration in the supine position, and the contraction thickness was measured in the straight leg raise position. The frequency was 7.5 ㎐, and the transducer head was transversely positioned 25 ㎜ anteromedial to the midway point between the 12th rib and the iliac crest. The transducer head was maneuvered until the sharpest images of all of the abdominal muscles (EO, IO, and TrA) were obtained. Three scans were taken on the right side of the abdominal muscles in their relaxed state in reference to a predetermined benchmark. The scanning location at the pretest was marked on a transparent sheet for the posttest in order to ensure identical placement throughout the entire experiment. To control for the potential influence of respiration on muscle thickness, the images were consistently acquired at the end of the expiration, which was determined through visual inspection of the ultrasound image. The image data acquired were stored, and the muscle thickness (㎝) was measured using an on screen caliper. The thicknesses of all three muscles were defined by drawing a vertical reference line that was located 2.5 ㎝ from the left edge (the muscle-fascia junction) of the TrA (Whittaker, 2008). An immediate readout of the mus-

Table 2. EMG muscle activity of the rectus femoris muscle at pre-post test (N=46)

Variable		Experimental group (n_1=23)	Control group (n_2=23)	Group effect F(1,44)	Group effect p	Time effect F(1,44)	Time effect p	Interaction effect F(1,44)	Interaction effect p
Muscle activity (%)	Pretest	39.35±16.24[a]	43.26±18.52	66.314	.000	.296	.589	30.212	.000
	Posttest	70.04±16.26	50.43±20.74						

[a]mean±standard deviation.

Table 3. Rectus femoris muscle thickness at rest and ratio at pre- and post-intervention (N=46)

Variable		Experimental group (n_1=23)	Control group (n_2=23)	Group effect F(1,44)	Group effect p	Time effect F(1,44)	Time effect p	Interaction effect F(1,44)	Interaction effect p
RF[a] at rest (㎜)	Pretest	6.69±1.86[b]	6.95±2.60	.082	.776	.024	.877	3.895	.055
	Posttest	7.18±2.49	6.53±2.61						
RF Ratio[c] (%)	Pretest	14.34±10.22	14.24±10.66	.183	.671	187.688	.000	8.071	.007
	Posttest	30.56±12.18	27.99±9.24						

[a]rectus femoris, [b]mean±standard deviation, [c]ratio (contraction-rest/rest).

cle thickness was displayed on the screen and stored for further analysis. Data that were unacceptable due to movement artifact were discarded, and the scan was then repeated. The ratio calculation gave the percentage change in the thickness. In this study, for the RF and all listed abdominal muscles were calculated by muscle contraction-muscle rest/muscle rest.

Statistical analysis

The results are expressed as mean±standard deviation. The normal distribution of the sample was tested using the Kolmogorov-Smirnov test, which showed a normal distribution for all variables. Two-way analysis of variance was used to assess the main effects (group and time effects) and the interaction effects on the muscle activation of the RF muscle and the muscle thickness of the RF and abdominal muscles, including the TrA, IO, and EO muscles at pre- and post-test of intervention, respectively. The collected data were analyzed using SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA). The level of statistical significance was set at a $p<.05$.

Results

There was a significant interaction effect (F=30.212, p=.000), group effect (F=66.314, p=.000), and time effect (F=0.296, p=.589) for RF muscle activation in sit-to-stand exercise with WB-EMS (Table 2). These results indicate that the EMG muscle activity of the RF showed remarkable improvement compared to that without the WB-EMS, that was attributable to sit-to-stand using WB-EMS.

Significant differences in RF muscle thickness at ratio (contraction to rest) were found in the interaction effect (F=8.071, p=.007), group effect (F=.183, p=.671), and time effect (F=187.688, p=.000) between the two groups (Table 3). This finding suggests that the muscle thickness of the RF showed effective gains in increase, which in turn further supports the neuromuscular strengthening training of the WB-EMS.

No significant differences in abdominal muscle thickness at the rest position were found between the two groups (Table 4). However, significant differences in the TrA and IO of the abdominal muscle thickness at ratio were found between the two groups (Table 5). TrA muscle thickness at ratio were found in interaction effect (F=5.474, p=.024) and time effect (F=398.440, p=.000), IO muscle thickness at ratio were found in interaction effect (F=24.151, p=.000) and time effect (F=251.365, p=.000) (Table 5). This finding suggests that the deep muscle of the abdominal muscle, such as the TrA or IO, in the sit-to-stand with WB-EMS showed improvement

Table 4. TrA, IO, EO muscle thickness at rest position in pre-post test (N=46)

Variable		Experimental group (n_1=23)	Control group (n_2=23)	Group effect F(1,44)	Group effect p	Time effect F(1,44)	Time effect p	Interaction effect F(1,44)	Interaction effect p
TrA[a] at rest (㎜)	Pretest	3.36±.74[b]	3.53±.76	1.134	.293	2.295	.137	.487	.489
	Posttest	3.45±.93	3.77±.97						
IO[c] at rest (㎜)	Pretest	8.48±1.99	8.68±2.57	.104	.749	.001	.972	.000	.996
	Posttest	8.48±2.17	8.69±2.54						
EO[d] at rest (㎜)	Pretest	5.59±1.28	6.40±1.43	4.519	.039	5.265	.027	.023	.880
	Posttest	5.83±1.10	6.68±1.64						

[a]rectus femoris, [b]mean±standard deviation, [c]internal oblique, [d]external oblique.

compared to that without the WB-EMS in terms of the ratio of the muscle contraction.

Discussion

This study aimed to measure the muscle activity of the RF muscle, representing a muscle of the lower extremity and sit-to-stand movement, and the muscle thickness in the RF muscle and abdominal muscles before and after sit-to-stand exercise with WB-EMS. As anticipated, our results demonstrated a positive effect of the muscle activity of the RF muscle, and the muscle thickness ratio of the RF and the deep muscle of the abdominal muscle, such as the TrA or IO, in the experimental group wearing the WB-EMS.

In this study, improved muscle activity was observed to a greater extent in the experimental group after EMS training. The present muscle activity parameter findings showed that the RF muscle (39% MVIC → 70% MVIC) improved by approximately 79% after intervention. Additionally, in the control group without EMS, the RF muscle activity was increased by 16%. Importantly, the muscle activity of the RF is in line with the finding by Babault et al (2007), who demonstrated that the strengthening effect of sit-to-stand training improved by 23% in rugby players after a 12-week EMS with weight training. In general, muscle activity and muscle strengthening are known to be strongly correlated (Husted et al, 2018). The improvement in muscle activity of the quadriceps after 6 weeks of low-frequency EMS training has been previously reported to be 11% (Deley and Babault, 2014). Additionally, Herrero et al (2010) found that groups with weight training combined with 4-week EMS had a 9% increase in the strength of the quadriceps muscle. Kemmler et al (2016) showed that leg-extensor strength was similar to the group after 16 weeks of WB-EMS training combined with resistance exercise.

It can be extrapolated that improvement in the activation of type Ⅱ muscle fiber may have been the result of the recruitment rate of motor unit changes when electrical stimulation was combined with muscle contraction, neurophysiologically (Maffiuletti et al,

Table 5. TrA, IO, EO muscle thickness at ratio in pre-post test (N=46)

Variable		Experimental group (n1=23)	Control group (n_2=23)	Group effect F(1,44)	Group effect p	Time effect F(1,44)	Time effect p	Interaction effect F(1,44)	Interaction effect p
TrA[a] Ratio (%)	Pretest	20.97±17.25[b]	20.65±16.95	.137	.713	398.440	.000	5.474	.024
	Posttest	37.70±21.93	33.88±19.98						
IO[c] Ratio (%)	Pretest	25.49±17.90	23.98±16.87	.472	.496	251.365	.000	24.151	.000
	Posttest	34.94±21.28	28.95±17.89						
EO[d] Ratio (%)	Pretest	15.63±14.02	14.11±14.86	.005	.943	.307	.582	.466	.498
	Posttest	15.29±12.93	17.31±16.23						

[a]rectus femoris, [b]mean±standard deviation, [c]internal oblique, [d]external oblique.

2000). Indeed, despite the evidence that electrical stimulation combined with muscle contraction can promote inactivation or tired motor mechanisms (Riley et al, 2008), in terms of time efficiency, the muscle strength improvement effect of rapidly increasing muscle contractility in a short time is increasing the interest in WB-EMS.

The effectiveness of EMS training can be also elucidated by quantitative US measurement. The thicknesses of the RF muscle at the ratio before the intervention were approximately 14%, and increased by approximately 30% after the intervention (114% improvement). Intervention related changes in altered muscle thickness were successfully quantified by US. This morphological improvement in muscle thickness was paralleled with increased activity of the RF muscle after WB-EMS intervention.

The improvements in muscle activity and muscle thickness in the experimental group may be explained by the transfer effect as a result of the strengthening of the leg muscles after EMS training. Importantly, the muscle cross-sectional area of the quadriceps muscle is in line with the finding by Nastsume et al (2018) and Gondin et al (2005) who demonstrated an increase in muscle morphological change as a result of the EMS training. The increase in quadriceps muscle thickness after neuromuscular electrical stimulation training in patients in an intensive care unit for 4 weeks has been previously reported to be 5% by Gruther et al (2010). Similarly, Deley and Babault (2014) reported that the muscle thickness of the quadriceps muscle was increased by 3% after 10 ㎐ low-frequency EMS training for 6 weeks (Deley and Babault, 2014). Furthermore, Raja et al (2019) found that the use of WB-EMS for 8 weeks resulted in a 10% increase in 1RM squat strength, and approximately a 20% increase in the 1RM torso rotational strength.

The thickness of the abdominal muscle showed changes at the contraction ratio of the deep core muscles, including the TrA and IO muscles. These findings further indicate that WB-EMS training may have biomechanically affected the RF muscle and selectively stimulated the deep core muscle of the abdominal muscle during sit-to-stand movement, thus leading to lumbar stabilization, which is a key contributor to sit to standing. Moreover, in agreement with the results of the current study, Coghlan et al (2008) found that the TrA muscle thickness was increased by 22% after EMS training. The increase in the thickness of the TrA and IO muscles after neuromuscular electrical stimulation training was reported to be 2 ㎐-22%, 5 ㎐-33%, and 8 ㎐-21% (TrA), and 2 ㎐-20%, 5 ㎐-22%, and 8 ㎐-19% (IO) by Cho et al (2016). The results of this study showed that there was significant change in deep abdominal wall thickness, including the TrA and IO muscles, despite the characteristics in the short application time of this study.

There are several limitations to this study. First, methodologically, the size of the ball placed between the knee joints of the subject during the sit-to-stand was uniformly applied without adapting to each subject's physical characteristics. Second, we could not observe a sufficient shape change of the muscles by only using a 30 minute intervention time and electric stimulation of 20 to 200 ㎐. Third, this study involved a relatively small number of subjects. Lastly, this study did not have a follow-up; thus, we cannot say whether the benefit was retained. Therefore, a study investigating the effects of WB-EMS training on a large number of subjects with longer interventions is needed in order to fully elucidate the clinical benefits for a wide range of subjects.

Conclusion

In conclusion, most of the previous EMS studies have relied on the use of only a few measurements, without considering the need for more scientific and quantitative measurements. Therefore, this study sought to investigate the effects of wearable WB-EMS devices on muscle activity using EMG and muscle thickness using US measurement tools. The results demonstrated a positive effect of muscle activity of the RF muscle of one of the lower extremity muscles, the muscle thickness of the contraction ratio of the RF muscle, and the deep abdominal muscles, the TrA and IO, after WB-EMS intervention.

References

Babault N, Cometti G, Bernardin M, et al. Effects of electromyostimulation training on muscle strength and power of elite rugby players. J Strength Cond Res. 2007;21(2):431-437. https://doi.org/10.1519/R-19365.1

Cho HK, Jung GS, Kim EH, et al. The effects of neuromuscular electrical stimulation at different frequencies on the activations of deep abdominal stabilizing muscles. J Back Musculoskelet Rehabil. 2016;29(1):183-189. https://doi.org/10.3233/BMR-150638

Coghlan S, Crowe L, McCarthyPersson U, et al. Electrical muscle stimulation for deep stabilizing muscles in abdominal wall. Conf Proc IEEE Eng Med Biol Soc. 2008:2756-2759. https://doi.org/10.1109/IEMBS.2008.4649773

Deley G, Babault N. Could low-frequency electromyostimulation training be an effective alternative to endurance training? An overview in one adult. J Sports Sci Med. 2014;13(2):444-450.

Doucet BM, Lam A, Griffin L. Neuromuscular electrical stimulation for skeletal muscle function. Yale J Biol Med. 2012;85(2):201-215.

Filipovic A, Kleinöder H, Dörmann U, et al. Electromyostimulation--a systematic review of the effects of different electromyostimulation methods on selected strength parameters in trained and elite athletes. J Strength Cond Res. 2012;26(9):2600-2614. https://doi.org/10.1519/JSC.0b013e31823f2cd1

Fritzsche D, Fruend A, Schenk S, et al. Electromyostimulation (EMS) in cardiac patients. Will EMS training be helpful in secondary prevention? Herz. 2010;35(1):34-40. https://doi.org/ 10.1007/s00059-010-3268-8

Gilleard W, McConnell J, Parsons D. The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. Phys Ther. 1998;78(1):25-32. https://doi.org/10.1093/ptj/78.1.25

Gondin J, Guette M, Ballay Y, et al. Electromyostimulation training effects on neural drive and muscle architecture. Med Sci Sports Exerc. 2005;37(8):1291-1299. https://doi.org/10.1249/01.mss.0000175090.49048.41.

Gregory CM, Bickel CS. Recruitment patterns in human skeletal muscle during electrical stimulation. Phys Ther. 2005;85(4):358-364.

Gruther W, Kainberger F, Fialka-Moser V, et al. Effects of neuromuscular electrical stimulation on muscle layer thickness of knee extensor muscles in intensive care unit patients: A pilot study. J Rehabil Med. 2010;42(6):593-597. https://doi.org/10.2340/16501977-0564

Herrero AJ, Martín J, Martín T, et al. Short-term effect of strength training with and without superimposed electrical stimulation on muscle strength and anaerobic performance. A randomized controlled trial. Part I. J Strength Cond Res. 2010;24(6):1609-1615. https://doi.org/10.1519/JSC.0b013e3181dc427e

Husted R, Bencke J, Hölmich P, et al. Maximal hip and knee muscle strength are not related to neuromuscular pre-activity during side cutting maneuver: A cross-sectional study. Int J Sports Phys Ther. 2018;13(1):66-76.

Kemmler W, Bebenek M, Engelke K, et al. Impact of whole-body electromyostimulation on body composition in elderly women at risk for sarcopenia: The training and electrostimulation trial (TEST-III). Age (Dordr) 2014;36(1):395-406. https://doi.org/10.1007/s11357-013-9575-2

Kemmler W, Schliffka R, Mayhew JL, et al. Effects of whole-body electromyostimulation on resting metabolic rate, body composition, and maximum strength in postmenopausal women: The training and electrostimulation trial. J Strength Cond Res. 2010;24(7):1880-1887. https://doi.org/10.1519/JSC.0b013e3181ddaeee.

Kemmler W, Teschler M, Weißenfels A, et al. Effects of whole-body electromyostimulation versus high-intensity resistance exercise on body composition and strength: A randomized controlled study. Evid Based Complement Alternat Med. 2016;9236809. https://doi.org/10.1155/2016/9236809

Kemmler W, von Stengel S. Whole-body electromyostimulation as a means to impact muscle mass and abdominal body fat in lean, sedentary, older female adults: Subanalysis of the TEST-III trial. Clin Interv Aging. 2013;8:1353-1364. https://doi.org/10.2147/CIA.S52337

Kendall FP, McCreary EK, Provance PG, et al. Muscle: Testing and Function, with Posture and Pain. 5th ed. Baltimore, Lippincott Williams & Wilkins, 2005:317-330.

Lexell J, Taylor CC, Sjöström M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. J Neurol Sci. 1988;84(2-3):275-294. httpss://doi.org/10.1016/0022-510x(88)90132-3

Lieber RL, Silva PD, Daniel DM. Equal effectiveness of electrical and volitional strength training for quadriceps femoris muscles after anterior cruciate ligament surgery. Orthop Res. 1996;14(1):131-138. https://doi.org/10.1002/jor.1100140121

Maffiuletti NA, Cometti G, Amiridis IG, et al. The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. Int J Sports Med. 2000;21(6):437-443. https://doi.org/10.1055/s-2000-3837.

Maffiuletti NA, Vivodtzev I, Minetto MA, et al. A new paradigm of neuromuscular electrical stimulation for the quadriceps femoris muscle. Eur J Appl Physiol. 2014;114(6):1197-1205. https://doi.org/10.1007/s00421-014-2849-2

Natsume T, Ozaki H, Kakigi R, et al. Effects of training intensity in electromyostimulation on human skeletal muscle. Eur J Appl Physiol. 2018;118(7):1339-1347. https://doi.org/10.1007/s00421-018-3866-3

Pichon F, Chatard JC, Martin A, et al. Electrical stimulation and swimming performance. Med Sci Sports Exerc. 1995;27(12):1671-1676.

Porcari JP, McLean KP, Foster C, et al. Effects of electrical muscle stimulation on body composition, muscle strength, and physical appearance. J Strength Cond Res. 2002;16(2):165-172.

Raja Hussain RNJ, Kee KM, Razman R, et al. Effects of whole-body electromyostimulation strength and batting velocity of female collegiate softball players. Malaysian Journal of Movement, Health & Exercise. 2019;8(1):175-184.

Riley ZA, Maerz AH, Litsey JC, et al. Motor unit recruitment in human biceps brachii during sustained voluntary contractions. J Physiol. 2008;586 (Pt 8):2183-2193. https://doi.org/10.1113/jphysiol.2008.150698

van Buuren F, Mellwig KP, Frund A, et al. Electrical myostimulation: Improvement of quality of life, oxygen uptake and left ventricular function in chronic heart failure. Rehabilitation (Stuttg). 2014;53(5):321-326. https://doi.org/10.1055/s-0033-1358734

van Buuren F, Mellwig KP, Prinz C, et al. Electrical myostimulation improves left ventricular function and peak oxygen consumption in patients with chronic heart failure: Results from the exEMS study comparing different stimulation strategies. Clin Res Cardiol. 2013;102(7):523-534. https://doi.org/10.1007/s00392-013-0562-5.

von Stengel S, Bebenek M, Engelke K, et al. Whole-Body Electromyostimulation to Fight Osteopenia in Elderly Females: The Randomized Controlled Training and Electrostimulation Trial (TEST-III). J Osteoporos. 2015;643520. https://doi.org/10.1155/2015/643520

Whittaker JL. Ultrasound imaging of the lateral abdominal wall muscles in individuals with lumbopelvic and sign of concurrent hypocapnia. Man Ther. 2008;13(5):404-410. https://doi.org/10.1016/j.math.2007.03.008

This article was received September 18, 2019, was reviewed September 18, 2019, and was accepted November 14, 2019.