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EFFECT OF WHOLE-BODY ELECTROMYOSTIMULATION ON ENERGY EXPENDITURE DURING EXERCISE

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ABSTRACT

Kemmler, W, von Stengel, S, Schwarz, J, and Mayhew, JL. Effect of whole-body electromyostimulation on energy expenditure during exercise. *J Strength Cond Res* 26(1): 240–245, 2012—The application of whole-body electromyostimulation (WB-EMS) in the area of fat reduction and body shaping has become more popular recently. Indeed, some studies prove positive outcomes concerning parameters related to body composition. However, there are conflicting data as to whether EMS relevantly impacts energy expenditure (EE) during or after application. Thus, the main purpose of the study was to determine the acute effect of WB-EMS on EE. Nineteen moderately trained men (26.4 ± 4.3 years) were randomly assigned to a typically used low-intensity resistance exercise protocol (16 minutes) with (85 Hz) and without WB-EMS. Using a crossover design, the same subjects performed both tests after completely recovering within 7 days. Energy expenditure as the primary endpoint of this study was determined by indirect calorimetry. The EE during low-intensity resistance exercise with adjuvant WB-EMS was significantly higher ($p = 0.008$) than that during the control condition (412 ± 60 vs. 352 ± 70 kcal; effect size; $d = 0.92$). This study clearly demonstrates the additive effect of WB-EMS on EE in moderately trained subjects during low-intensity resistance exercise training. Although this effect was statistically significant, the fast and significant reductions of body fat observed in recent studies suggest that the effect of WB-EMS on EE may still be underestimated by indirect calorimetry because of the inability of indirect calorimetry to accurately assess EE during “above-steady state conditions.” Although from a statistically point of view WB-EMS clearly impacts EE, the relatively small effect did not suggest a broad application of this device in this area. However, taking other positive outcomes of this technology into

account, WB-EMS may be a time-saving option at least for subjects unwilling or unable to exercise conventionally.

KEY WORDS muscle-stimulation, metabolic rate, $\dot{V}O_2$, RPE, crosssectional

INTRODUCTION

Time-saving, low-intensity “exercise” programs with impact on fitness and body composition are increasingly promoted by the Fitness industry. Whole-body electromyostimulation (WB-EMS) is a new training technology that fundamentally differs from the passive and locally applied classical EMS with mainly therapeutical aims. Modern WB-EMS devices differentially stimulate all main muscle groups (i.e., up to an area of $2,800 \text{ cm}^2$) simultaneously with dedicated intensity during slight movements and are thus increasingly applied within the health, beauty, and fitness segment. Besides the broad range of application as the central argument for WB-EMS, its time-saving, orthopedically gentle but highly favorable impact on body composition has been frequently stated (4). Indeed, the favorable effects of WB-EMS on body composition and fitness parameters have been reported in recent studies (14,15). Regarding (abdominal) body fat as a central predictor of metabolic and coronary heart diseases (19), WB-EMS was impressive with the rapid and significant decrease it produced in this risk factor.

However, because of the failure to generate positive effects on muscle coordination during passive EMS application (1), recent WB-EMS protocols focus on WB-EMS application during exercise or at least during slight movements (3,14,15, 26). Because volume and intensity of the applied “resistance exercise” protocols per se were presumably too short or low to explain the observed positive outcomes (14,15), the magnitude of the additional effect of WB-EMS during exercise is yet to be fully established.

In this context, the assessment of energy expenditure (EE) may be a good choice to use for validating the additional effects of WB-EMS during exercise. On reviewing the literature, it is seen that no study focuses on the effect of WB-EMS devices on EE; however, some studies with local EMS approaches may provide an insight into the effect of this

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26(1)/240–245

Journal of Strength and Conditioning Research
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method (2,5,8,10,11,24). Although, there is some evidence that locally applied EMS relevantly increases EE (10,24), one recent study (11) that used EMS devices able to stimulate larger muscle groups (i.e., both thigh and the rectus abdominus) at rest noted that none of the devices showed significantly higher oxygen consumption values compared with the non-EMS condition. It seems obvious, however, that WB-EMS stimulating simultaneously most or all main muscle groups with a dedicated intensity should be more effective in increasing EE than local or regional applications are. Further, an underlying feature of previous studies is that the effect of EMS was assessed only during static or passive conditions. However, as already stated, this more therapeutic approach fundamentally differs from the present WB-EMS protocols with dynamic exercises or at least slight movements to generate positive effects on muscle coordination, which was not achieved during passive EMS application as reported (1).

Therefore, the purpose of this study was to determine the additive effect of WB-EMS during dynamic “exercises” typically performed during commercial WB-EMS-sessions on EE. Our hypothesis was that the addition of WB-EMS to low-intensity exercises would significantly increase EE by one-third.

METHODS

Experimental Approach to the Problem

We used a randomized crossover design to address our hypothesis that the effect of WB-EMS on EE during low-intensity resistance exercises typically performed within a WB-EMS session was at least $\approx 33\%$ higher when compared with a non-WB-EMS control condition. Although somewhat arbitrary, this difference was selected because this predicted effect would be relevantly higher compared with those of other devices (i.e., Nordic Walking [22]) that also focus to increase EE during exercise. The selected protocol allowed each subject to serve as his own control. The assessment of our primary endpoint EE by indirect calorimetry (dependent variable) allowed the determination of the added real time effect of WB-EMS to the metabolic cost of each activity. Participant tests were supervised by the same assistants at the same time of the day (± 1 hour). The trial was conducted from May 2009 through July 2009.

Subjects

Nineteen recreationally active young men participated in the study. The subjects were recruited by announcements at the Institute of Sport Science and the Institute of Medical Physics at the University of Erlangen, Germany. Inclusion criteria included age between 20 and 40 years and a history of 5–8 hours of exercise per week during the past 2 years. Exclusion criteria included any medical condition that might endanger the subject during participation. Twenty subjects, all of them sport students or sport scientists with no specific background concerning strength or power training, responded (Table 1),

TABLE 1. Physical characteristics of our participants ($n = 19$).

Variable	Mean \pm SD	Min	Max
Age (y)	26.3 \pm 4.5	21	39
Body height (cm)	181.4 \pm 6.6	168	196
Body weight (kg)	77.7 \pm 7.2	66.1	86.6
Body mass index ($\text{kg}\cdot\text{m}^{-2}$)	23.6 \pm 1.5	21.2	25.9
Body fat (%)	11.7 \pm 3.4	5.1	19.5
$\dot{V}\text{O}_2\text{peak}$ ($\text{ml}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$)	55.7 \pm 7.5	48	62
Exercise volume ($\text{h}\cdot\text{wk}^{-1}$)	5.1 \pm 2.3	4	9
History of exercise (y)	9.6 \pm 6.4	2	20

but 1 subject was excluded because of acute health problems. Thus, 19 subjects were included. All study participants were informed of the experimental risk and gave written informed consent. A detailed pretest protocol asked subjects to maintain their habitual lifestyle and nutrition and to not exercise 48 hours before the tests. A detailed questionnaire, completed by all study participants prestudy, combined age, health status, medication, sociodemographic parameters and recent and present physical activity and exercise level or status. All 19 subjects performed both tests (with and without WB-EMS) of the trial according to the protocol. All the subjects stated that they rigidly adhered to our test and pretest protocol. The study protocol was approved by the Committee for the Review of Studies on Human Subjects of the university. Table 1 shows the characteristics of the subjects.

Procedures

Two tests with and without EMS conditions (described below) were performed. During both conditions, the subjects wore EMS equipment (Miha Bodytec, Augsburg, Germany) with the only difference between EMS and control trial being that during the control trial, the current was switched off. Besides an attempt to blind the participants, this procedure was chosen to ensure comparable sweating. Detailed instructions concerning pretest exercise, lifestyle, and nutritional habits were also provided. Therein, participants were instructed to avoid strenuous exercise 48 hours pretest and to maintain their normal caloric and liquid intake throughout the duration of the study. During all exercise tests, the room temperature was maintained constant at 20 to 22°C with a relative humidity of 40–50%.

Electromyostimulation. The subjects performed the guided and supervised low-intensity resistance protocols recently described (14) either with or without WB-EMS (Miha Bodytec). Briefly, this WB-EMS equipment enables the simultaneous

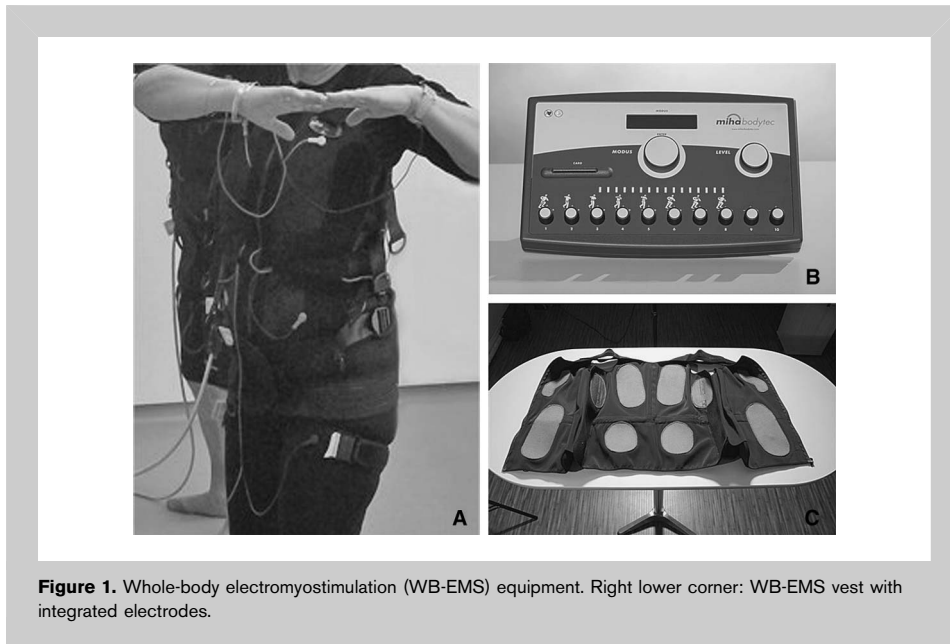


Figure 1. Whole-body electromyostimulation (WB-EMS) equipment. Right lower corner: WB-EMS vest with integrated electrodes.

activation of the muscles of 16 regions (e.g., upper legs, upper arms, gluteals, abdomen, chest, lower back, upper back, shoulder; total size of electrodes: $\approx 2,650 \text{ cm}^2$) with different dedicated intensities (Figure 1).

Generally, the exercise protocol of our trial closely copied the typical setting of commercial WB-EMS sessions with their low loading and low duration strategy. An electric current was applied with a frequency of 85 Hz intermittently with 4 seconds of activation and 4 seconds of rest (Table 2) at the subject's maximum tolerance limit. Five dynamic exercises for large muscle groups, typically performed during commercial WB-EMS sessions, were performed without any additional weights (Table 3, Figure 2) and were structured in 2 sets of 8 repetitions. Squat movements with a range of motion from 90 to 180° flexion of the knee joint were carried out during all exercises (Figure 2). Thus, the exercise protocol lasted 16 minutes, a duration typically followed during

commercial WB-EMS sessions. The performance of the exercises was synchronized with the 4 seconds on–4 seconds off EMS cycle. The subjects were carefully instructed by research assistants on how to perform the exercises. For consistency, a swivel chair was adjusted for each subject to ensure a maximum of 90° knee flexion during squatting. Further, the participants were acoustically and visually guided by a video (Figure 2) that exactly controlled the 4-second exercise–4-second rest rhythm of the resistance protocol. Because of the increasing tolerability of the current intensity during the session, the current intensity was adjusted (at the

subject's maximum tolerance levels) after 2, 8, and 13 minutes. At least 4 days of rest was given between both tests.

Measurements

Anthropometry. We measured height, weight, and body composition. The body composition was determined using multifrequency, whole-body impedance technique (In Body 720, Biospace, Seoul, Korea). The coefficient of variation for body fat as assessed by our bio impedance technique device was 3.6% in our laboratory.

Energy Expenditure. Indirect calorimetry was used to determine EE (18). The $\dot{V}O_2$, VCO_2 , V_E were continuously determined breath by breath using an Oxicon Mobile (Viasys, Conshohocken, PA, USA) open spirometric system. Gas calibration was carried out each morning, and volume calibration was performed before each test. The coefficient of variation for $\dot{V}O_2$ in our laboratory was 2.5% for corresponding treadmill protocols.

To assess the relative perceived exertion, the subjects were asked immediately after both tests to state a rating of perceived exertion (RPE) on a Borg scale ranging from 1 (very, very easy) to 20 (very, very hard).

Statistical Analyses

Sample size calculation was based on EE. Although we speculate that differences were much higher (>33%), our calculation was based on a 10% EE difference between EMS and control condition. Thus, 18 subjects per test condition were required for a 5% error probability with 80% statistical power. The study was designed as a per-protocol analysis; however, no subject dropped out during the study.

Besides power and effect size (ES) calculation, SPSS 18.0 (SPSS Inc., Chicago IL, USA) was used for all statistical

TABLE 2. The WB-EMS protocol of the trial.*

Parameters	WB-EMS protocol
Stimulation frequency	85 Hz
Impulse duration	4 s
Impulse break	4 s
Pulse breadth	350 μs
Impulse type	Bipolar
Duration	16 min

*WB-EMS = whole-body electromyostimulation.

TABLE 3. Exercises performed with and without WB-EMS.*†

Exercise	Primary loaded region
1. Squat and biceps curl	Leg extensors, leg flexors, gluteals, elbow flexors
2. Squat and arm extension	Leg extensors, leg flexors, gluteals, arm extensors
3. Squat and crunch	Leg extensors, leg flexors, gluteals, abdomen
4. Squat, latissimus pulleys (down) and shoulder press (up)	Leg extensors, leg flexors, gluteals, arm flexor, arm extensor, shoulder, chest, upper back
5. Squat, butterfly (down) and reverse fly (up)	Leg extensors, leg flexors, gluteals, chest, upper back

*WB-EMS = whole-body electromyostimulation.

†Exercises were carried out in a dynamic mode without additional weights (Figure 2).

procedures. Normal distribution was checked by the Kolmogorov-Smirnov test, and homogeneity of variance was investigated by Levine's *F* test. Concerning our main endpoint, dependent on the normal distribution of the variable, a *T*-Test was used to determine differences between both conditions. All tests were 2-tailed, and the statistical significance was accepted at $p \leq 0.05$. To determine the magnitude of the difference, ESs according to the Cohen *d* procedure (7) were calculated.

RESULTS

All the subjects performed their tests according to the protocol. No injuries or undesired side effects occurred during the tests.

Energy expenditure was 17% higher during the exercise protocol with WB-EMS application ($412 \pm 60 \text{ kcal}\cdot\text{h}^{-1}$) compared with the noncurrent exercise protocol (352 ± 70

$\text{kcal}\cdot\text{h}^{-1}$). The differences between both protocols were statistically significant ($p = 0.008$, ES, $d = 0.92$).

The RPE was significantly higher ($p = 0.001$, ES, $d = 1.69$) during WB-EMS application (Borg scale: 14.7 ± 1.5 ; \approx "hard"), than during noncurrent conditions (Borg scale: 11.9 ± 1.8 ; \approx "light to moderate").

Taken together, our results for EE were significant but much lower than expected; thus, we have to reject our primary hypothesis that the addition of WB-EMS to low-intensity exercises would increase EE by \geq one-third.

DISCUSSION

The development of time-saving and effective exercise protocols and training technologies is a central aim of the fitness industry. Hereby, most emphasis is traditionally placed on "body shaping" and especially on the reduction of body fat. In this context, WB-EMS becomes increasingly popular not only for subjects unable but also for those unwilling to perform time consuming, intense exercise programs. However, the effect of this alternative training technology on parameters closely related to weight or fat loss remains to be established. Thus, the purpose of this trial was to determine the effect of a WB-EMS protocol typically performed in commercial settings on EE. Summarizing our results, the additional application of WB-EMS significantly increases EE of a low-intensity resistance exercise protocol that is typically performed during commercial WB-EMS-sessions; however, the approximately 20% higher EE during WB-EMS was far below our expectation. This difference is within the upper range of the effect of "Nordic Walking" (vs. walking without poles at corresponding speed) that was reported to vary between approximately 8 and 22% (6,17,21,22).

Large methodological differences become apparent, which prevents a meaningful comparison of our data with studies using local EMS approaches (2,5,8,24). This especially refers to the local application with small electrodes, the immobilization of the resting muscle group (by fixation of the limb), the application of low current intensity (e.g., 25% of the MVC), and the choice of different endpoints (e.g., energy-rich



Figure 2. Shoulder press combined with the squat exercise with whole-body electromyostimulation equipment during the resistance protocol. All the exercises were performed in a dynamic mode.

phosphagens) in other studies. However, 2 studies (10,24) determined the effect of “regional” EMS on oxygen consumption at rest and noted an EE increase of approximately $75 \text{ kcal}\cdot\text{h}^{-1}$ while stimulating lower extremities with low frequency EMS (8 and 20 Hz, respectively). A more recent study (11) compared 2 commercially available EMS devices during the resting condition, and although one of their applications consisted of 10 electrodes that stimulated the abdomen area and both thighs, the authors reported negligible effects on oxygen consumption (control: 3.73 vs. EMS: $3.75 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). According to these results, EMS-induced EE increase would have resulted in only a 1- to $2\text{-kcal}\cdot\text{h}^{-1}$ increase. These negligible increases in EE induced by the EMS methods are surprising and not in line with the findings of Simoneau (24), Hamada et al. (10), and this study. It can be assumed that these older local devices are not comparable with modern WB-EMS technology that affects several different large regions with regionally variable intensity levels.

One may argue that the rather unspectacular differences invoked by WB-EMS during exercise observed in our study ($\approx 20\%$) may not justify the application of this rather exclusive and expensive technology. However, we assume that the real effect of WB-EMS on EE may have been underestimated. Although indirect calorimetry has been described as a valid method to quantify EE (18), the extramitochondrial fraction of energy production most important at higher intensity rates cannot be determined by this method (16,20). In this context, Hamada et al. (10) noted a substantial involvement of glycolytic energy production in their thigh EMS procedure. This was paralleled by a significant increase in lactic acid during EMS compared with that during voluntary exercise at an identical $\dot{V}O_2$ level. Scott et al. (23) observed that oxygen consumption was a valid tool to determine EE for resistance exercise training only during “steady state conditions.” This may support our contention of an underestimation in this study. However, although we have intensively reviewed the literature, we are not aware of a more accurate real time assessment method of EE.

This problem of accuracy concerning the above steady-state condition of exercise, however, would not result in a systematic bias that affects EMS and non-EMS conditions similarly. It is obvious that the intensity of our non-EMS protocol can be classified best as low-moderate, whereas EMS application comparable with our 85-Hz protocol was reported to result in very high muscular tensions (i.e., “supramaximum recruiting of muscle fibers”) and preferential activation of glycolytic type 2 fibers (reversal of the Hennemann size principle” [4]) resulting in metabolic demands that cannot be assessed adequately by indirect calorimetry (20). Because of the lack of more accurate procedures, it is very difficult to judge the magnitude of this effect. However, to correspondingly get a rough idea, Robergs et al (20) used multiple regression analysis to predict the metabolic cost of resistance training at higher loads (65 and 70% 1RM; i.e., “above-steady state

conditions”). The authors reported predicted EEs 2–3 times (15.3 and $16.3 \text{ kcal}\cdot\text{min}^{-1}$) higher as compared with results of studies that determined metabolic costs at identical intensities by indirect calorimetry.

Besides acute effects of WB-EMS during resistance exercise, short- and long-term postexercise effects on EE were also important for a definite conclusion of the relevance of WB-EMS to improve overweight or obesity. Resting metabolism and/or excessive postexercise energy consumption (EPOC) have been reported to be increased up to 24–48 hours after endurance and resistance exercise (9,13,27). Considering that magnitude of the EPOC was primarily related to exercise intensity (16), we speculate that the more pronounced loading during WB-EMS should result in more distinct EPOC increments corresponding to higher EE. Although a recent review (16) stated that EPOC comprises at best 6–15% of the net total energy cost during exercise, this factor may further contribute to the favorable effect of WB-EMS observed in longitudinal studies. “Long-term” effects of WB-EMS may refer to highly significant increases of muscle mass in elderly men noted previously for the WB-EMS protocol (14) evaluated in this study, with well-established implication on resting metabolic rate (25). Indeed, a recent study of our working group determined the positive effects of WB-EMS on resting metabolism in elderly trained women (15).

The main limitation of this study may be the potentially limiting validity of indirect calorimetry to adequately assess EE during “above-steady state conditions.” Although this may prevent more distinct results, one ought to realize that because of the higher overall intensity during WB-EMS with correspondingly higher extramitochondrial energy production, this effect rather led to an underestimation of the WB-EMS effect on EE and thus to more discreet results. Further, although the effect of EPOC on EE is reported to be rather limited (16), an evaluation of this effect may have strengthened our project.

Vice versa the strong point of the study was the high methodological quality regarding our main hypothesis (12). Besides design, randomization, and blinding strategy, special emphasis was placed on the standardization of the test protocols. This included the implementation of training videos to ensure proper execution of the exercises. Furthermore, our cohort was rather homogeneous according to gender, age, physical fitness, and exercise history, although no subject was specialized on endurance or resistance exercise.

In conclusion, although this study determined a “significant effect” (i.e., significant differences between both conditions) of WB-EMS during dynamic low-intensity resistance exercise on EE, the ES was below our expected value and did hardly reflect the impressive effects on body fat parameters reported by longitudinal WB-EMS studies (14,15). One central reason for this discrepancy may be the inability of indirect calorimetry to adequately assess EE during “above-steady state conditions.” However, until no more accurate real time assessment method of EE is provided, this problem will remain. Prospectively, when

we consider WB-EMS as an alternative means of exercise training, a plethora of questions concerning the effectiveness and mode of action of this technique on different endpoints and populations remain. With regard to EE, future studies should manipulate loading parameters of EMS (e.g., current frequency, intensity, mode of exercise, training frequency) to determine the most effective WB-EMS protocols.

PRACTICAL APPLICATIONS

Contrary to the known primarily therapeutic and athletic application of classical local EMS, WB-EMS is a new comprising training technology that allows extensive wide field of application. In Germany, >1,200 commercial suppliers of the health, beauty, and fitness segment use WB-EMS devices, thereby approximately reaching 50,000 end users. The majority of these end users focus on fat reduction and body shaping. Thus, it is important for the exercise and fitness specialists to evaluate the effectiveness of a typical WB-EMS protocol on parameters (EE during exercise) closely related to weight and fat reduction. Taken together, although significant, the effect of WB-EMS on acute EE during exercise remains below our expectations possibly because of methodological reasons. However, WB-EMS is a smooth, time-saving option (temporarily or continuously) for subjects either unable or unwilling to exercise conventionally (10). Thus, WB-EMS technology ought to be seriously considered by fitness and exercise specialists and corresponding end users.

ACKNOWLEDGMENTS

We gratefully acknowledge the support of Miha Bodytec. None of the authors has any conflict of interest. Further the results of the study do not constitute endorsement of the product by the authors or the National Strength and Conditioning Association.

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