Phys. Act. Child. 2024; 1(2): e490070 Journal Homepage https://doi.org/10.61186/pach.2024.490070.1041

Physical Activity in Children
ISSN: 2783-5391

Original Article

Comparison of Whole-Body Electrical Stimulation with Aerobic Exercise on Body Composition and Serum Irisin Level in Overweight Adolescents

Gabrial Pouzesh Jadidi *

Ph.D in Sport Physiology, Department of Sport Physiology, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran.

Corresponding Author: Gabrial Pouzesh Jadidi. Ph.D in Sport Physiology, Department of Sport Physiology, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran. Email: jpoozesh@uma.ac.ir

Received: 22 November, 2024; **Revised:** 20 December, 2024; **Accepted:** 24 December, 2024; **Published:** 25 December, 2024.

Abstract

Introduction: Obesity stands out as a significant health-related challenge that affects individuals across different age groups.
Objective: The objective of the current study was to investigate the impact of eight weeks of moderate-intensity aerobic exercise combined with whole-body electrical muscle stimulation (EMS) on the levels of irisin hormone, fat-free mass, and body fat percentage in overweight adolescents.
Methods: This research employed a semi-experimental design in terms of methodology and was practical in its aims. A total of 52 overweight teenagers were voluntarily selected and randomly assigned to two groups: one engaging in aerobic exercise with EMS and the other participating in aerobic exercise alone (control group). The study was conducted in three phases: pre-test, intervention, and post-test. During the pre-test phase, body fat percentage and fat-free mass were assessed using a body composition measuring device (model 3, manufactured in South Korea), while irisin levels were determined using the ELISA method. Subsequently, the experimental group underwent eight weeks of EMS combined with aerobic exercise, participating in three sessions each week, while the control group performed only the aerobic exercise regimen.
Results: The results from the analysis of covariance indicated that the combination of whole-body EMS and aerobic exercise significantly improved body composition and increased serum irisin levels in overweight adolescents.
Conclusion: Overall, it appears that incorporating EMS into aerobic exercise serves as an effective adjunct, facilitating improvements in body mass index (BMI) and reductions in body fat through the elevation of irisin levels.

Keywords: Electrical Stimulation, Irisin Hormone, Aerobic Exercise, Body Composition, Obesity

How to Cite: Gabrial Pouzesh Jadidi. Comparison of Whole-Body Electrical Stimulation with Aerobic Exercise on Body Composition and Serum Irisin Level in Overweight Adolescents. Phys. Act. Child. 2024;1(2):80-85. doi: 10.61186/pach.2024.490070.1041

1. Introduction

The contemporary lifestyle, characterized by unhealthy dietary habits and a lack of physical activity, has contributed to a rise in the incidence of various diseases and obesity (1). Obesity stands out as a significant health-related challenge that affects individuals across different age groups. Adolescence is recognized as a crucial phase in human development, during which behavioral changes can significantly impact nutritional status (2). The rise of technology has resulted in reduced physical activity levels, with physical inactivity being closely linked to obesity and overweight, which are pressing health concerns (1,3). Recent research highlights a concerning global increase in obesity rates. This condition, classified as a chronic disease associated with disorders in fat metabolism, has seen a marked rise since the early 20th century. In both developed and developing nations, the prevalence of obesity has escalated to the extent that some experts have termed it a hidden epidemic. Today, obesity is not only viewed in relation to chronic diseases such as cardiovascular issues, diabetes, hypertension, hyperlipidemia, and cancer but is also recognized as a significant risk factor in its own right. Surveys and studies conducted in Iran reveal a growing prevalence of obesity among the youth, adolescents, and adults in the country. Estimates suggest that over 24 million individuals in Iran are either overweight or obese (4).

Skeletal muscle is increasingly recognized as an endocrine organ that produces and releases proteins known as myokines (5). These myokines are essential in modulating metabolic functions within the muscle and influencing the endocrine activities of various tissues and organs, such as the liver, adipose tissue, and brain. Given that skeletal muscle represents a significant portion of the human body, the impact of myokines on overall metabolic processes is likely to be considerable (6). The primary trigger for the synthesis and secretion of myokines is the contraction of skeletal muscle, and the changes in muscle tissue resulting from exercise are, in part, facilitated by these myokines. Recent studies have uncovered a range of myokines, with a particular subset being activated specifically through muscle contraction (7). These discoveries highlight the potential role of contraction-induced myokines in alleviating insulin resistance and addressing metabolic disorders like obesity. To date, several myokines have been recognized for their contributions to regulating glucose uptake, enhancing insulin sensitivity, and promoting fat metabolism (8).

Irisin is a myokine primarily released into the bloodstream by muscle cells during contractions, with significant influence from adipose tissue. This myokine is believed to enhance energy expenditure by facilitating the transformation of white adipose tissue (WAT) into brown adipose tissue (BAT), a process driven by the activation of the uncoupling protein 1 (UCP1) gene (9). This conversion generates heat, contributing to fat mass reduction, improved glucose tolerance, and decreased insulin resistance (10). The precursor to irisin is a protein known as fibronectin type 3 (FNDC5)-containing protein 5. Upon cleavage of this precursor, irisin is produced. Physical exercise elevates levels of peroxisome proliferator-activated receptor-gamma coactivator 1-alpha (PGC1-α), which in turn boosts the expression of the FNDC5 gene. This cascade results in increased irisin production, promoting the conversion of white adipose tissue into brown adipose tissue. The activation of brown adipose tissue is associated with positive metabolic outcomes and may help mitigate the adverse effects of obesity and excess weight (11). The transformation of white adipocytes into brown adipocytes, along with heightened thermogenic activity, enhances insulin sensitivity and contributes to weight loss (12).

Recent research indicates that engaging in regular physical activity serves as a significant, cost-effective, and accessible intervention that can diminish body fat, inflammation, and the incidence of heart diseases, ultimately aiding in the management of obesity-related conditions (13). Aerobic exercises have been shown to enhance cardiorespiratory fitness and lower risk factors among adolescents (14). Aerobic exercise encompasses sports activities that are sustained continuously for an extended duration (exceeding three minutes). A training method that has garnered attention recently is whole body electrical muscle stimulation (EMS), which utilizes a series of electrodes integrated into a specialized vest. When worn, this vest applies EMS to the major muscle groups, engaging them simultaneously and establishing a specific kinetic chain during the execution of physical movements.

Whole body EMS has a significant impact on body composition, enhances strength through neuromuscular adaptation, improves intermuscular coordination and muscle size, and boosts energy levels (15). A key benefit of EMS is its ability to induce muscle contractions without the need for direct muscle engagement. Furthermore, studies indicate that an EMS session can elevate glycolytic metabolism and increase the levels of serum and plasma lipids, positioning it as a viable strategy for enhancing lipid metabolism within muscle tissue. For instance, research (16) demonstrated that EMS results in a rise in the concentration of free fatty acids in the bloodstream. It appears that muscle contractions induced by EMS demand greater energy expenditure compared to voluntary contractions, potentially yielding effects comparable to physical activity. Additionally, another study (17) found that whole body EMS contributes to increased energy expenditure. This energy enhancement is particularly beneficial for young men. Consequently, considering that EMS promotes energy consumption through muscle contractions, and recognizing the role of irisin in boosting energy metabolism by converting white fat to brown fat, the researcher proposed that combining whole body EMS with aerobic exercise may offer superior benefits for improving body composition and enhancing irisin secretion compared to aerobic exercise alone.

A review of previous studies revealed that EMS resulted in more significant alterations in the expression of ACE and ACTN3 (18). Additionally, a study (19) examined the impact of EMS on energy expenditure and body composition in postmenopausal women, concluding that EMS was more effective than both endurance and resistance exercises in enhancing body composition. Furthermore, EMS was found to reduce local abdominal fat thickness in healthy young women. Another study (20) demonstrated that whole-body EMS positively influenced sarcopenia parameters and localized fat accumulation. It has been reported that EMS increased irisin levels, thereby improving glucose metabolism in inactive middle-aged women (21). However, there is a lack of research comparing whole-body EMS with aerobic exercise in overweight adolescents. Given the rapid and significant hormonal changes during adolescence, it is essential to conduct such research to address this scientific gap and leverage the findings to highlight the benefits of whole-body EMS for adolescents.

2. Methods

The current investigation utilized a semi-experimental design and was applied in nature concerning its aims. The statistical population comprised overweight adolescents living in Tehran, with the average age of male participants recorded at 13.92±1.7 years and a body mass index (BMI) exceeding 25 kg/m^2. Inclusion criteria mandated that participants possess a BMI greater than 25, fall within the adolescent age bracket, and be free from any significant health issues. In contrast, the exclusion criteria included individuals who demonstrated a lack of interest in participating and those who missed more than three training sessions. The sample size was calculated using Gpower based on a statistical power of 0.80, an alpha level of 0.05, an effect size of 0.40, resulting in a total of 52 participants. As a result, 52 overweight adolescents were chosen and randomly allocated into two groups, each consisting of 26 participants.

2.1. Measurements

Height was assessed utilizing a SECA height meter, while weight was recorded with a digital scale manufactured in China. The plasma irisin level was determined through the ELISA method using a kit from Bioassay Technology Laboratory, also from China. Body composition was evaluated with a body composition device, model 2020, produced in Korea. Additionally, EMS apparatus, branded Miha bodytec and made in Germany, comprised vests, belts, and electrodes.

2.2. Instruction

Initially, a briefing session was conducted to outline the research objectives, the potential applications of its findings, the anticipated benefits and side effects, as well as the methodology and duration of the exercises for the teenage participants. Subsequently, teenagers with a BMI exceeding 25 kg/m^2, who had a medical history free of illness, infection, or drug use, were purposefully selected and randomly assigned to research groups. In the pre-test phase, measurements of height, weight, and body composition were taken using a body composition device, and plasma irisin levels were assessed through blood sampling. Over the course of eight weeks, the experimental group engaged in three 40-minute sessions of aerobic exercise each week, along with two 20-minute sessions of whole-body EMS. Meanwhile, the control group participated in the same aerobic exercises as the experimental group. Finally, in the post-test phase, body composition and plasma irisin levels were measured again, mirroring the pre-test assessments (19,20).

Table 1. Training Protocol.

Week	Training Duration	Intensity	Warm-up	Cool-Down
1	25	5 minutes	65% heart rate	5 minutes
2	25	5 minutes	65% heart rate	5 minutes
3	35	5 minutes	70% heart rate	5 minutes
4	35	5 minutes	70% heart rate	5 minutes
5	40	5 minutes	75% heart rate	5 minutes
6	40	5 minutes	75% heart rate	5 minutes
7	45	5 minutes	80% heart rate	5 minutes
8	45	5 minutes	85% heart rate	5 minutes

2.3. Aerobic Training Protocol

The aerobic training regimen consisted of three sessions per week over a duration of 8 weeks, during which participants engaged in a running program. The intensity and duration of the training were progressively increased at the conclusion of each phase. In the initial two weeks, participants exercised for 25 minutes at an intensity of 65% of their maximum heart rate. From weeks three to six, the duration was extended to 35 minutes, with intensity levels ranging from 65% to 75% of the maximum heart rate. Finally, in weeks seven and eight, participants exercised for 40 minutes at an intensity of 75% to 85% of their maximal heart rate (22).

2.4. Whole Body Electrical Stimulation Protocol

The whole-body EMS protocol involved two training sessions each week, with each session lasting 20 minutes. Participants were advised to have at least two days of rest between sessions, culminating in a total of 16 training sessions over an 8-week period. The EMS targeted the muscles through bipolar impulses set at a frequency of 85 Hz and an amplitude of 350 msec, with each stimulation lasting 6 seconds followed by a 4-second recovery period. Eight muscle groups were engaged, including those in the forearm, chest, upper back, latissimus dorsi, lower back, hip, and thigh. During the stimulation phase, participants executed two sets of light dynamic movements, each consisting of ten repetitions. These movements included trunk flexion and extension, moderate squats, butterfly movements, and underarm stretches, with the intensity of EMS adjusted individually for each session. Overload was applied as needed (23).

2.5. Blood Sampling Protocol

Blood sampling was conducted on two separate occasions, prior to and following the test. All subjects underwent fasting and provided samples between 9 and 10 in the morning. A laboratory technician collected the blood from the left brachial vein while the subjects were seated. During this procedure, a blood volume of 10 cc was obtained, and the samples were centrifuged at a speed of 3,000 revolutions per minute for a duration of 20 minutes to facilitate the separation and collection of serum. The resulting serum was subsequently stored at a temperature of -70 degrees Celsius. The sensitivity was determined to be 0.095 ng/mL, with a coefficient of variation within the test exceeding 8% and a coefficient of variation outside the test exceeding 10%.

2.6. Data Analysis

In this section, indicators such as mean and standard deviation were used for descriptive data analysis; According to the establishment of statistical assumptions of covariance analysis, this statistical method was used for data analysis at the level of 0.05 in SPSS software version 26.

3. Results

Table 2 presents the average and standard deviation of body mass index, fat percentage, and irisin levels for two research groups during both the pre-test and post-test phases.

Table 2. BMI Indicators, fat Percentage and Irisin Level.

Variable	Whole Body Electrical Stimulation and Aerobic Exercise		Aerobic Exercise	
	Pre-test	Post-test	Pre-test	Post-test
BMI (K/m^2)	30.2±6.4	26.1±3.8	30.2±2.1	28.2±2.1
Fat percentage	31.1±8.6	26.2±4.4	35.3±4.3	27.3±8.4
Irisin (ng/ml)	29.8±8.4	33.7±8.9	32.8±6.7	33.8±9.4

An initial review of the assumptions underlying the analysis of covariance revealed that the necessary conditions for this analysis were satisfied. These conditions include the normal distribution of the data, the homogeneity of variances, a linear relationship between the dependent variable and the covariate, as well as the homogeneity of the slopes of the regression lines. The analysis of covariance results presented in Table 3 indicate that the combination of whole body EMS with aerobic exercise resulted in a significant reduction in the body mass index (BMI) of overweight adolescents when compared to the control group engaging solely in aerobic exercise ($\eta=0.49$, $p<0.001$, $F(8, 49)=1$). Furthermore, this combined exercise regimen also led to a notable decrease in the fat percentage among overweight teenagers compared to the control group (η=0.14, p=0.007, F(8, 49)=8.02). Lastly, the integration of whole body EMS with aerobic exercise was associated with a significant increase in irisin levels in overweight adolescents relative to those participating only in aerobic exercise (η=0.31, p<0.001, F(1, 49)=22.09).

Table 3. Results of Covariance Analysis.

Variable	SS	df	MS	F	P-Value	η^2
BMI (K/m^2)	72.6	1	72.6	48.83	P<0.001	0.49
	72.9	49	1.48			
Fat Percentage	13.07	1	13.07	8.02	P=0.007	0.14
	79.88	49	1.63			
Irisin (ng/ml)	82.8	1	82.8	22.09	P<0.001	0.31
	183.6	49	3.74			

4. Discussion

The results of the present study demonstrate that the integration of whole-body EMS with aerobic activities led to a decrease in both body fat percentage and BMI in overweight adolescents. This finding is consistent with earlier research (19,20,24,25). However, it contrasts with the findings of a previous study (26), who reported no significant difference in body composition between groups engaging in aerobic exercise with whole body EMS and those participating solely in aerobic exercise. This discrepancy may be attributed to the differing durations of the exercise interventions; another study (26) implemented a 12-week program, whereas the present study involved an 8-week regimen. The results of this study suggest that whole body EMS can serve as an effective supplementary training method alongside voluntary exercises. By activating the maximum muscle movement units, it fosters unique adaptations and enhances metabolic rates. Consequently, it appears that the combination of EMS and aerobic exercise contributes to reductions in BMI and body fat percentage through increased metabolic activity.

For instance, a study (27) investigated the impact of EMS during moderate-intensity cycling and found that EMS can elicit a greater intensity of muscle activation compared to standard activity. This increased activation of contractile fibers results in heightened metabolic rates. Additionally, another study (28) indicated that EMS contributes to an elevation in average energy expenditure. Nevertheless, the findings of the current study do not contradict the meta-analysis conducted by a study (19), which concluded that EMS does not influence fat mass. To clarify this discrepancy, it is important to consider the differing methodologies employed in the two studies; the present research incorporated whole-body EMS alongside aerobic activities.

The findings of the current study indicate that the combination of whole-body EMS and aerobic exercise resulted in an elevation of irisin levels. This outcome aligns with the findings of a previous study (29). Obesity is recognized as one of the most prevalent metabolic disorders, with both obesity and insulin resistance significantly contributing to the development of type 2 diabetes. Research conducted by another study (30) demonstrated that serum levels of irisin in individuals nearing the threshold of type 2 diabetes decline as the disease progresses. The secretion of irisin in humans has been shown to enhance obesity management and glucose tolerance while decreasing insulin resistance (31). Body fat is categorized into two types: brown and white. Historically, it was believed that brown adipose tissue was absent in adult humans; however, it is now understood that a small quantity of brown fat exists in adults. During physical activity, a protein known as irisin is released, which has the capability to convert white fat into brown fat, thereby contributing to the reduction of obesity, diabetes, and various other health issues.

Irisin and physical exercise may significantly influence the quantity of brown adipose tissue in the body (9). Generally, muscle activity appears to enhance the synthesis of PGC-1α, which subsequently elevates the production of FNDC5, ultimately leading to the generation of irisin. As a result, irisin may be crucial in decreasing body weight and fat percentage among overweight adolescents. Unlike most muscle-derived substances, irisin enters the bloodstream and targets adipocytes, where it initiates specific biochemical signals that convert white fat into brown fat (32). This process seems to be part of the molecular adaptations associated with exercise training that are mediated by irisin (33). Irisin additionally improves insulin sensitivity by reducing endoplasmic reticulum stress and supporting the viability of pancreatic beta cells and GLUT4. Moreover, it promotes the expression of uncoupled protein 1 (UCP1) in adipocytes, thereby aiding in the process of fat browning via the mitogen-activated protein kinase (MAPK) and extracellular regulated kinase (ERK) signaling pathways (15). Irisin also facilitates mitochondrial biogenesis through the regulation of PPARA gene expression and mitochondrial transcription. Furthermore, other studies have demonstrated its efficacy in decreasing fat mass while enhancing oxidative capacity and promoting lean body mass (21).

4.1. Conclusion

EMS, when combined with aerobic exercise, appears to offer significant advantages for enhancing body composition. The increase in irisin protein may serve as a potential mechanism underlying the benefits of this exercise modality. Consequently, it is recommended that trainers and personal trainers incorporate whole body EMS as an adjunctive strategy to improve body composition. However, one limitation of the current study is the duration of the research process, which may have diminished the motivation and effort of the participants. Additionally, while participants were instructed to adhere to their usual dietary habits, precise control over their eating patterns was not feasible. Furthermore, the study focused on overweight adolescents, whose responses to exercise regimens may differ from those of other age groups due to rapid hormonal fluctuations. Therefore, it is advisable for future researchers to explore similar studies across various age groups and to investigate the effects of different frequencies and intervals of EMS.

Acknowledgments

The author is grateful to all participants who participated in this research.

Footnotes

Authors' Contribution: This study was carried out solely by the corresponding author.

Conflict of Interests: The researcher confirms that there is no conflict of interests in this study with any participant.

Data Availability: The data that support the findings of this study are openly available upon request from the corresponding author.

Ethical Approval: The author confirms that all steps and requirements of this study comply with ethical guidelines. Participants were informed about the characteristics of the study and gave written informed consent.

Funding/Support: This research received no external funding.

Informed Consent: Informed written consent was obtained from all participants.

Supplementary Information accompanies this paper at doi: 10.61186/pach.2024.490070.1041

ORCID iD

Gabrial Pouzesh Jadidi https://orcid.org/0000-0002-9547-8642

References

1. Veugelers PJ, Fitzgerald AL. Prevalence of and risk factors for childhood overweight and obesity. CMAJ. 2005;173(6):607-13. [PubMed ID: 16157724]. [PubMed Central ID: PMC1197160]. doi: 10.1503/cmaj.050445.
2. McKeown A, Nelson R. Independent decision making of adolescents regarding food choice. Int J Consum Stud. 2018;**42**(5):469-77. doi: 10.1111/ijcs.12446
3. Gallo Marin B, Aghagoli G, Lavine K, Yang L, Siff EJ, Chiang SS, Salazar-Mather TP, Dumenco L, Savaria MC, Aung SN, Flanigan T, Michelow IC. Predictors of COVID-19 severity: A literature review. Rev Med Virol. 2021;**31**(1):1-10. [PubMed ID:32845042]. [PubMed Central ID: PMC7855377]. doi: 10.1002/rmv.2146.
4. Rashidi H, Erfanifar A, Latifi SM, Payami SP, Aleali AM. Incidence of obesity, overweight and hypertension in children and adolescents in Ahvaz southwest of IRAN: Five-years study. Diabetes Metab Syndr. 2019;**13**(1):201-205. [PubMed ID: 30641697]. doi: 10.1016/j.dsx.2018.05.021.
5. Febbraio MA, Pedersen BK. Contraction-induced myokine production and release: is skeletal muscle an endocrine organ? Exerc Sport Sci Rev. 2005;**33**(3):114-9. [PubMed ID: 16006818]. doi: 10.1097/00003677-200507000-00003.
6. Whitham M, Febbraio MA. The ever-expanding myokinome: discovery challenges and therapeutic implications. Nat Rev Drug Discov. 2016;**15**(10):719-29. [PubMed ID: 27616294]. doi: 10.1038/nrd.2016.153.
7. Raschke S, Eckardt K, Bjørklund Holven K, Jensen J, Eckel J. Identification and validation of novel contraction-regulated myokines released from primary human skeletal muscle cells. PLoS One. 2013;**8**(4):e62008. [PubMed ID: 23637948]. [PubMed Central ID: PMC3634789]. doi: 10.1371/journal.pone.0062008.
8. Eckardt K, Görgens SW, Raschke S, Eckel J. Myokines in insulin resistance and type 2 diabetes. Diabetologia. 2014;**57**(6):1087-99. [PubMed ID: 24676645]. doi: 10.1007/s00125-014-3224-x.
9. Boström P, Wu J, Jedrychowski MP, Korde A, Ye L, Lo JC, Rasbach KA, Boström EA, Choi JH, Long JZ, Kajimura S, Zingaretti MC, Vind BF, Tu H, Cinti S, Højlund K, Gygi SP, Spiegelman BM. A PGC1-α-dependent myokine that drives brown-fat-like development of white fat and thermogenesis. Nature. 2012;**481**(7382):463-8. [PubMed ID: 22237023]. [PubMed Central ID: PMC3522098]. doi: 10.1038/nature10777.
10. Shoukry A, Shalaby SM, El-Arabi Bdeer S, Mahmoud AA, Mousa MM, Khalifa A. Circulating serum irisin levels in obesity and type 2 diabetes mellitus. IUBMB Life. 2016;**68**(7):544-56. [PubMed ID: 27220658]. doi: 10.1002/iub.1511.
11. Perakakis N, Triantafyllou GA, Fernández-Real JM, Huh JY, Park KH, Seufert J, Mantzoros CS. Physiology and role of irisin in glucose homeostasis. Nat Rev Endocrinol. 2017;**13**(6):324-337. [PubMed ID: 28211512]. [PubMed Central ID: PMC5878942]. doi: 10.1038/nrendo.2016.221.
12. Park KH, Zaichenko L, Brinkoetter M, Thakkar B, Sahin-Efe A, Joung KE, Tsoukas MA, Geladari EV, Huh JY, Dincer F, Davis CR, Crowell JA, Mantzoros CS. Circulating irisin in relation to insulin resistance and the metabolic syndrome. J Clin Endocrinol Metab. 2013;**98**(12):4899-907. [PubMed ID: 24057291]. [PubMed Central ID: PMC3849667]. doi: 10.1210/jc.2013-2373. Erratum in: J Clin Endocrinol Metab. 2014;**99**(5):1910.
13. Tjønna AE, Stølen TO, Bye A, Volden M, Slørdahl SA, Odegård R, Skogvoll E, Wisløff U. Aerobic interval training reduces cardiovascular risk factors more than a multitreatment approach in overweight adolescents. Clin Sci (Lond). 2009 Feb;**116**(4):317-26. [PubMed ID: 18673303]. doi: 10.1042/CS20080249.
14. Liao J, Huang J, Wang S, Xiang M, Wang D, Deng H, Yin H, Xu F, Hu M. Effects of exercise and diet intervention on appetite-regulating hormones associated with miRNAs in obese children. Eat Weight Disord. 2021 Mar;**26**(2):457-465. [PubMed ID: 32072570]. doi: 10.1007/s40519-020-00869-9. Epub 2020 Feb 18.
15. Teschler M, Wassermann A, Weissenfels A, Fröhlich M, Kohl M, Bebenek M, von Stengel S, Kemmler W. Short time effect of a single session of intense whole-body electromyostimulation on energy expenditure. A contribution to fat reduction? Appl Physiol Nutr Metab. 2018;**43**(5):528-530. [PubMed ID: 29253351]. doi: 10.1139/apnm-2017-0602.
16. Hioki M, Takahashi H, Saito A, Imai M, Yasuda H. Effect of electromyostimulation training on intramuscular fat accumulation determined by ultrasonography in older adults. Eur J Appl Physiol. 2023;**123**(2):271-282. [PubMed ID: 36260185]. [PubMed Central ID: PMC9580431]. doi: 10.1007/s00421-022-05074-3.
17. Perez-De-Arrilucea-Le-Floc'h UA, Dote-Montero M, Carle-Calo A, Sánchez-Delgado G, Ruiz JR, Amaro-Gahete FJ. Acute Effects of Whole-Body Electromyostimulation on Energy Expenditure at Resting and during Uphill Walking in Healthy Young Men. Metabolites. 2022;**12**(9):781. [PubMed ID: 36144186]. [PubMed Central ID: PMC9504893]. doi: 10.3390/metabo12090781.
18. Ma F, Yang Y, Li X, Zhou F, Gao C, Li M, Gao L. The association of sport performance with ACE and ACTN3 genetic polymorphisms: a systematic review and meta-analysis. PLoS One. 2013;**8**(1):e54685. [PubMed ID: 23358679]. [PubMed Central ID: PMC3554644]. doi: 10.1371/journal.pone.0054685.
19. Kemmler W, Shojaa M, Steele J, Berger J, Fröhlich M, Schoene D, von Stengel S, Kleinöder H, Kohl M. Efficacy of Whole-Body Electromyostimulation (WB-EMS) on Body Composition and Muscle Strength in Non-athletic Adults. A Systematic Review and Meta-Analysis. Front Physiol. 2021;**12**:640657. [PubMed ID: 33716787]. [PubMed Central ID: PMC7952886]. doi: 10.3389/fphys.2021.640657.
20. 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**:1353-64. [PubMed ID: 24130433]. [PubMed Central ID: PMC3795534]. doi: 10.2147/CIA.S52337.
21. Rashti BA, Mehrabani J, Damirchi A, Babaei P. The influence of concurrent training intensity on serum irisin and abdominal fat in postmenopausal women. Prz Menopauzalny. 2019;**18**(3):166-173. [PubMed ID: 31975984]. [PubMed Central ID: PMC6970417]. doi: 10.5114/pm.2019.90810.
22. McMurray RG, Forsythe WA, Mar MH, Hardy CJ. Exercise intensity-related responses of beta-endorphin and catecholamines. Med Sci Sports Exerc. 1987;**19**(6):570-4. [PubMed ID: 2963188].
23. Reljic D, Konturek PC, Herrmann HJ, Neurath MF, Zopf Y. Effects of whole-body electromyostimulation exercise and caloric restriction on cardiometabolic risk profile and muscle strength in obese women with the metabolic syndrome: a pilot study. J Physiol Pharmacol. 2020;**71**(1). [PubMed ID: 32554843]. doi: 10.26402/jpp.2020.1.08.
24. Wittmann K, Sieber C, von Stengel S, Kohl M, Freiberger E, Jakob F, Lell M, Engelke K, Kemmler W. Impact of whole body electromyostimulation on cardiometabolic risk factors in older women with sarcopenic obesity: the randomized controlled FORMOsA-sarcopenic obesity study. Clin Interv Aging. 2016;**11**:1697-1706. [PubMed ID: 27920508]. [PubMed Central ID: PMC5123721]. doi: 10.2147/CIA.S116430.
25. Porcari JP, Miller J, Cornwell K, Foster C, Gibson M, McLean K, Kernozek T. The effects of neuromuscular electrical stimulation training on abdominal strength, endurance, and selected anthropometric measures. J Sports Sci Med. 2005;**4**(1):66-75. [PubMed ID: 24431963]. [PubMed Central ID: PMC3880086].
26. Ghannadi S, Halabchi F, Maleklou F, Tavakol Z, Rajabian Tabesh M, Bala D, Alizadeh Z. The effect of 6 weeks electrical muscle stimulation training and aerobic exercise on body composition of

overweight women: a randomized controlled study. Sport Sci Health. 2022;**18**(4):1387-95. doi: 10.1007/s11332-022-00910-7

27. Watanabe K, Taniguchi Y, Moritani T. Metabolic and cardiovascular responses during voluntary pedaling exercise with electrical muscle stimulation. Eur J Appl Physiol. 2014;**114**(9):1801-7. [PubMed ID: 24867595]. doi: 10.1007/s00421-014-2906-x.
28. Grosset JF, Crowe L, De Vito G, O'Shea D, Caulfield B. Comparative effect of a 1 h session of electrical muscle stimulation and walking activity on energy expenditure and substrate oxidation in obese subjects. Appl Physiol Nutr Metab. 2013;**38**(1):57-65. [PubMed ID: 23368829]. doi: 10.1139/apnm-2011-0367.
29. Ghalamsiah N, Nourshahi M. Acute effects of high-intensity functional training with or without whole-body electromyostimulation on serum irisin and brain-derived neurotrophic factor in overweight individuals. Sci Sport. 2023;**38**(8):799-806. doi: 10.1016/j.scispo.2022.08.004
30. Choi YK, Kim MK, Bae KH, Seo HA, Jeong JY, Lee WK, Kim JG, Lee IK, Park KG. Serum irisin levels in new-onset type 2 diabetes. Diabetes Res Clin Pract. 2013 Apr;**100**(1):96-101. [PubMed ID: 23369227]. doi: 10.1016/j.diabres.2013.01.007. Epub 2013 Jan 29.
31. Seale P. Transcriptional control of brown adipocyte development and thermogenesis. Int J Obes (Lond). 2010 Oct;34 Suppl 1:S17-22. [PubMed ID: 20935660]. doi: 10.1038/ijo.2010.178.
32. Islam MR, Valaris S, Young MF, Haley EB, Luo R, Bond SF, Mazuera S, Kitchen RR, Caldarone BJ, Bettio LEB, Christie BR, Schmider AB, Soberman RJ, Besnard A, Jedrychowski MP, Kim H, Tu H, Kim E, Choi SH, Tanzi RE, Spiegelman BM, Wrann CD. Exercise hormone irisin is a critical regulator of cognitive function. Nat Metab. 2021;3(8):1058-1070. doi: 10.1038/s42255-021-00438-z. Erratum in: Nat Metab. 2021;**3**(10):1432. [PubMed ID: 34417591]. [PubMed Central ID: PMC10317538]. doi: 10.1038/s42255-021-00476-7.
33. Li R, Xia J, Zhang XI, Gathirua-Mwangi WG, Guo J, Li Y, McKenzie S, Song Y. Associations of Muscle Mass and Strength with All-Cause Mortality among US Older Adults. Med Sci Sports Exerc. 2018 Mar;**50**(3):458-467. [PubMed ID: 28991040]. [PubMed Central ID: PMC5820209]. doi: 10.1249/MSS.0000000000001448.