REVIEW

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Efficacy of Whole-Body Electromyostimulation on Muscle Strength, Anthropometrics and Performance in Active Young Adult Populations: A Systematic Review

Wirksamkeit der Ganzkörper-Elektromyostimulation auf Muskelkraft, Anthropometrie und Leistung in aktiven Bevölkerungsgruppen: Eine systematische Übersicht

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Summary

- **Background:** Whole-body electromyostimulation (WB-EMS) is a relatively new training modality with most of the research being conducted on sedentary or elderly populations due to its high exercise acceptance, relatively easy of use (always supervised by qualified professionals), and time-effective nature of the modality. Results in these populations suggest WB-EMS to be a viable alternative to other training methods. It would be inappropriate to extrapolate the observed effects from this population to active and trained young people, since the scientific community recognizes that these individuals require significantly greater training stimuli to elicit a response in performance variables.
- **Objective:** The objective of this study was to provide a systematic review of existing research in WB-EMS training on muscle strength, anthropometrics, and performance variables in active young adult populations.
- **Methods:** A literature search was performed using the databases of Scopus, Google scholar, Web of Science and PubMed (search date 26.05.2023). The studies were then analyzed for duplicates and relevance to the search criteria.
- **Results and Conclusion:** This study suggests that WB-EMS does not offer superior training adaptations compared to other training methods in active populations, with clear guidelines outlining the most effective practices for WB-EMS needing to be established. It is inconclusive as to whether WB-EMS training interventions may be as effective as other types of training at achieving positive adaptations in muscle mass, strength and power, and performance variables, such as sprint speed, and change of direction speed.

KEY WORDS:
WB-EMS, Training Method, Training Adaptation, Muscle Mass, Sprint Speed, Direction Speed

Introduction

Whole-body electromyostimulation (WB-EMS) is a training methodology that has gained increasing popularity over the last decade where an individual wears a suit with electrodes in to stimulate multiple muscle groups simultaneously. The key benefit of WB-EMS when compared to EMS is that, due to stimulating multiple regions at the same time, it is significantly more time efficient (13).

The most extensively researched and commonly adopted training modality to build strength is traditional resistance training (11). Whilst being proven to have an abundance of health and performance benefits, it is time-intensive and can be severely affected by individuals suffering from "kinesiophobia", which is a fear of movement due to pain. It is thought within the scientific community that WB-EMS may help overcome this cycle and remove barriers to exercise due to the low loads and intensities used during the movements (29). It must be noted that this training modality has an extremely high exercise acceptance which is consistently noted in the scientific literature (13). This theory may also be applied to high performing athletes, who are prone to aches and pains in muscles after high match and training loads (22), and thus, WB-EMS may be a tool that could be used in such periods (20).

The benefits of WB-EMS seem to be positive for a variety of different health variables and populations. Some studies (12, 16, 17) found that this technology may help reduce abdominal body fat, adiposity and can increase fat free mass in elderly, obese women when compared to active control groups. This suggests that WB-EMS can be an excellent tool to help combat sarcopenia and reduce abdominal adiposity, which is a risk factor for many diseases, such as cardiovascular disease, metabolic syndrome, and some cancers (2, 3) with the study by Kim and Jee (2020) even finding a significant decrease in cancerous biomarkers in the WB-EMS group compared to the control. WB-EMS has also shown promise as a treatment for lower back pain (18, 28), with these studies both finding this approach to have similar outcomes to traditional treatment concepts.

Most studies on the effects of WB-EMS and EMS on performance variables have historically been conducted in inactive or elderly populations. Longitudinal studies, such as one conducted by Von Stengel and Kemmler (2018) showing that in a large population of males aged 27-89, WB-EMS had a significant effect on increasing maximum leg strength but found that this increase is blunted as age increases (28). Similar trend is also observed within standard resistance exercise regimens (23), due to a decreased ability to innovate these fibers and a flattening of the muscle fiber pennation angles. Studies have also found that WB-EMS can have a significant effect on muscle hypertrophy in non-active and elder populations (14). The systematic review by Kemmler ›

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and colleagues (17) observed significant results with large effect sizes of WB-EMS training on muscle mass parameters. It must be stated that these effects are in inactive individuals. It would be inappropriate to extrapolate the observed effects from this systematic review to active young adult individuals, as it is recognized within the scientific community that these individuals require significantly greater training stimuli to elicit a response in performance variables, such as muscle mass.

As stated earlier, previous reviews (15, 16) have demonstrated the application of WB-EMS technology in training in detail, however, we consider it appropriate to conduct an updated review due to the necessity to analyze the effect of WB-EMS training only on active young adult active populations. The purpose of this systematic review is to analyze the use of WB-EMS for young active adult populations and to determine whether this methodology has a viable use in eliciting adaptations within this population without detriment to the safety or health of the individuals.

Methodology

This study was designed following the instructions proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (21).

Search Strategy and Data Sources

The location of the studies that have evaluated training with WB-EMS that are analyzed in this systematic review has been carried out by searching the Scopus, Google Scholar, Web of Science, and PubMed databases, with the first search being conducted on May 23, 2023, and the last search being conducted on May 26, 2023. The keywords used were "whole body electromyostimulation" OR "wb-ems" OR "global electrical stimulation" AND "Hypertrophy" OR "Strength" OR "Performance".

The results of the searches were imported into bibliographic management software (EndNote Online), with duplicate studies being removed. A rough assessment was then performed on the selected studies to determine their relevance to the topic, with irrelevant ones being removed. Afterwards, a complete read of the remaining studies was undertaken to establish the final selection of the studies to be included in the review. The selection process that was applied to the articles that were studied was based on the selection criteria mentioned above, including types of intervention, types of variable measurement, and types of protocol. The results of the entire search, screening, and selection process are presented in the PRISMA diagram (figure 1).

Duplicate articles, studies that were not experimental, that were not written in English, that analyzed acute effects of WB-EMS training, or that did not analyze the effects of using WB-EMS on any variable in concept 2 (skeletal muscle hypertrophy, skeletal muscle strength, or performance variables) were eliminated. A series of exclusion criteria were also applied to guarantee the selection of studies specifically designed to evaluate the effects of WB-EMS training on the development of physical abilities in active trained populations:

- Studies carried out in children under 16 years of age and adults over the age of 45.
- Animal studies
- Studies carried out on obese or injured populations.
- Studies carried out on inactive populations (sedentary cohort)

Search, Screening, and Selection of Results

The search of different databases identified 147 articles. After the removal of duplicates, the titles, and abstracts of 88 articles were analyzed to determine whether they met the inclusion criteria. After this second screening, which resulted in 71 articles being discarded because they dealt with subjects different from the focus of the study and a further article being discarded as the full study could not be found online, 15 texts remained. Of these, 4 additional articles were excluded as systematic reviews. Finally, 11 articles were included in the systematic review. The search, screening, and selection process is reflected in the PRISMA flow chart (figure 1).

Results

Characteristics of Sample

A total of 324 subjects were analyzed across all studies included in this review, with 163 being males (1, 5, 6, 7, 19, 27, 30) and 161 being females (4, 5, 10, 11, 22). All individuals were healthy and physically active; however, 238 participants were competitive athletes of varying levels, 42 were classified as recreational athletes, and the remaining 44 were sport students (table 1).

Description of Included Studies

Amaro-Gahete et al. (2) analyzed the effects of WB-EMS training in twelve male recreational runners. The assessment measures for this study were: $\dot{V}O_2$max, aerobic and gas exchange thresholds, running economy, vertical jump, and anthropometric parameters. The sample was formed by experimental group (EG, n=6) and control group (CG, n=6), who continued their habitual running training as normal. Participants in EG had improvements in $\dot{V}O_2$max, aerobic and gas exchange thresholds, and vertical jump height (countermovement jump and abakalov jump), whereas no significant changes were observed in the control group.

D'Ottavio et al. (6) evaluated the effect of 2 different WB-EMS training protocols with differing electrical parameters on strength and power when compared to a resistance circuit training control over a 6-week period in active university students. Twenty-two subjects were involved in this study, with thirteen males and nine females. Participants were randomly assigned to one of three groups: a low frequency WB-EMS group (n=6), a high frequency WB-EM group (n=8), or a circuit training control group (n=8). The research protocol was carried out over a 6-week period, with 2 sessions being conducted per week. The control group performed 3 sets of dynamic strength circuit training, supervised by a fitness coach, with progressive loading undertaken each session. Both WB-EMS treatments performed the same training regime of ten different bodyweight isometric exercises for 2 minutes per exercise, resulting in a total training time of 20 minutes. No progressive overload was taken for either WB-EMS session. The results of this study found all protocols significantly improved bench press and squat strength and power to a similar degree, with no differences found between protocols.

Dörmann et al. (5) analyzed the effects of WB-EMS training on performance variables (muscle strength, power, sprint speed, change of direction speed). Twenty-two physically active females were split into two groups: a strength training group superimposed with WB-EMS (EG, n=11), compared to a strength training control (TG, n=11). This protocol of a 4-week intervention period consisting of two training sessions per week for both groups, one strength focussed session lasting 25 minutes, and one jumping and sprinting. Both groups had the exact same exercise selection and protocol, with the only difference being the WB-EMS exercises were superimposed with WB-EMS (set to 70% of the individual's pain threshold) whilst the control group exercises utilized external loads. No significant differences were found between groups for maximum strength or power for the leg press, leg extension, and leg curl, change of direction speed, straight sprint speed, vertical or horizontal jumps. It also found the control group to have a significantly lower contact time of the drop jump, and lower split time of change of direction speed, contrary to the hypothesis.

Filipovic et al. (7) investigated the effects of a WB-EMS intervention program on strength, sprint speed, jumping and kicking capacity, as well as biomarkers (CK and IGF-1) of muscle damage and hypertrophy in elite soccer players. Twenty-two players with a minimum of 5 years of experience with systematic strength training, but with no WB-EMS training experience, were randomized into two groups: a WB-EMS group (n=12), or a jump-training control group (n=10). The interventions were conducted twice per week for 14 weeks, with testing taking place before the intervention, and after weeks 7 and 14 to establish progress. The results found the 14-week EG intervention to significantly improve maximal leg press strength, linear sprinting, change of direction speed, vertical jump performance, and kicking velocity. No improvements were found in the CG. The EG also had significantly higher CK levels compared to the CG, but no differences were found between groups in IGF-1.

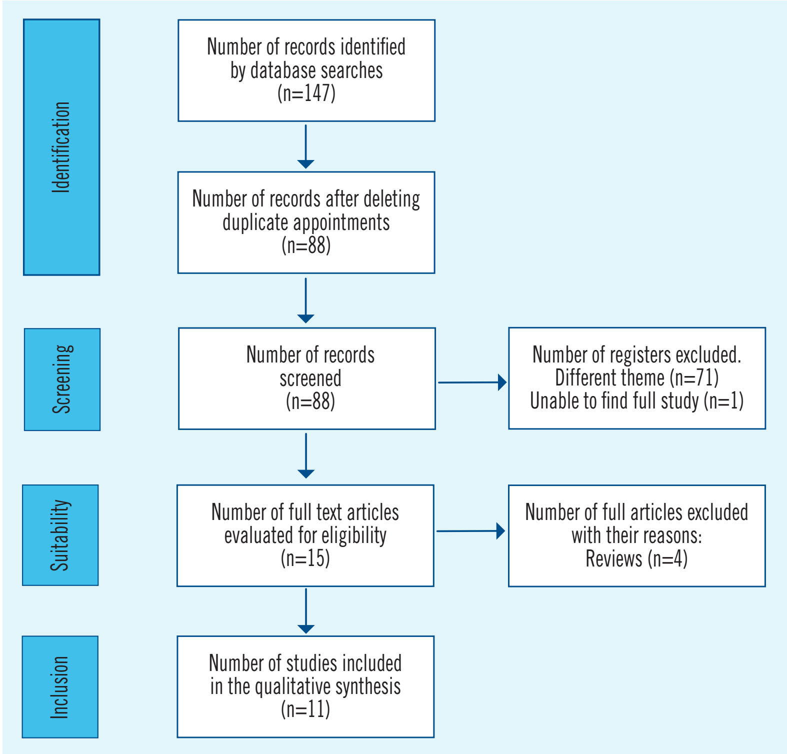

Figure 1
PRISMA flow.

Filipovic et al. (8) conducted a further study on the effects of WB-EMS training on muscle strength and hypertrophy in male soccer players. They took twenty-eight football players, all participants had strength training experience. These participants were randomly assigned to one of three groups: a control group (CG, n=8), a WB-EMS group (EG, n=10), or a jump training group (TG, n=10). Both the EG and the TG performed 3 x 10 squat jumps twice per week over a 7-week period on top of their normal soccer routines, with the only difference being the EG was superimposed using WB-EMS, with an intensity of 16-19 on the BORG scale of RPE. The CG just performed their regular training. The results of this study found that the EG had significant increases in maximal strength in leg press and leg curl, as well as a small increase in the diameter of type II myofibers, none of which were observed in the TG or CG.

Hussain et al. (11) examined the effects of WB-EMS compared to dry swing (swinging bats of different weights without hitting a ball) training on muscle strength and batting velocity in female collegiate softball players. Forty female collegiate softball players were randomly assigned to two groups: a dynamic WB-EMS training program + dry swing training group (EG, n=20) or a dry swing control group (CG, n=20). Both groups undertook 100 dry swings three times per week for eight weeks, with the EG conducting a further dynamic WB-EMS training session after each dry swing practice session. The study found the EG to have significantly increased their predicted 1RM bench press and squats compared to the control, which showed no significant improvements. Both groups were found to significantly increase torso rotational strength and batting velocity, with significant between group differences being reported in favor of the EG.

Hussain et al. (12) assessed the effect of WB-EMS training on muscle strength in female collegiate softball players compared to traditional resistance training. Sixty female collegiate softball players were randomly assigned to one of three groups: a WB-EMS group (EG, n=20), a traditional resistance training group (TG, n=20), or a control group (CG, n=20). All groups performed normal swing training practice, three times per week for a duration of eight weeks, with the EG performing a WB-EMS training session after each session. The TG group also performed the same exercises as the WB-EMS group after the swing practice, using additional external loads instead of WB-EMS. Both the EG and the TG groups undertook a progressive overloading approach to the exercises throughout the intervention to ensure accurate adaptations to a real training program. The study found that whilst both the EG and TG groups resulted in increased significantly in lower and upper body strength (squat and bench test), the increases for the TG group were significantly higher than EG.

Sadeghipour et al. (25) investigated the effect of WB-EMS training on body composition and maximal strength compared to resistance training in trained women. They took thirty trained women and divided them randomly into three groups: one WB-EMS training group (EG, n=10), one strength training group (TG, n=10), and one control group (CG, n=10). The CG did not have any regular planned physical activity, so they went about their normal activities as usual, whereas the EG and TG groups performed 2 sessions per week over a 6-week intervention period. Regarding body composition no significant observations were found between groups. For maximal strength, both the EG and the TG had similar improvements when compared to the control group.

Schuhbeck et al. (28) analyzed the influence of WB-EMS training on a variety of performance variables in amateur ice hockey players of different competitive statuses (the hobby league players averaged 1-2 training sessions and one game per week, and the district league players averaged 2-3 training sessions and 1-2 games per week). Thirty male ice hockey players were randomly assigned to one of two groups (A or B) in a randomized cross-over design study: WB-EMS sessions were carried out once a week for 12 weeks for each group with a subsequent 4-week WB-EMS pause. The results of this study found that the WB- ›

EMS training resulted in significant increases in jump power, decreases in 10m skate time, increases in maximum isokinetic force at 300°/s and 60°/s, and increases in vertical jump height. No significant change was found in post training shot speed. After the cessation of the WB-EMS protocols, training adaptations were found to have regressed. There is a greater potential for improvement for hobby sportsmen, because of the lower training potential of professional athletes, their training effect should be less pronounced than with leisure athletes.

Wirtz et al. (31) conducted a study investigating the effects of a jump training program superimposed with WB-EMS on physiological and cellular adaptations for endurance performance compared to a standard jump training program in amateur football players. This study randomly divided twenty-eight amateur football players into three groups: a WB-EMS jump training group (EG, n=10), a standard jump training group (TG, n=10), or a control group (CG, n=8). All groups continued their standard weekly football training, which consisted of 3.2 ± 1.0 training sessions and one match per week. The EG and TG both performed 2 training sessions per week for 7 weeks consisting of 3 sets of 10 maximal squat jumps, the only difference between groups was that the EG was superimposed with WB-EMS. The results of this study found no intra-or-inter-group differences between any of the intervention protocols for $\dot{V}O_2$max, time to exhaustion, La_{max}, or MCT density.

Ludwig et al. (20) analyzed the effect of a 10-week WB-EMS intervention on muscle strength in elite youth soccer players compared to a traditional strength training protocol. Thirty male soccer players from a youth academy (aged 15-17 years) participated in this study. The participants typically trained 4 times, one of which being a 45-minute athletic training session, 20 minutes of this being strength training, and played one match per week. The players were split into two groups: a conventional strength training control group (CG, n=12), and a strength training superimposed with WB-EMS group (EG, n=18). Both groups performed a 20-minute strength training session consisting of static and dynamic exercises once per week for 10 weeks in place of their usual strength training sessions. A ten-week superimposed whole-body electromyostimulation training improves the muscle strength of leg, hip, and trunk to a greater extent than a pure athletic strength training.

Discussion

Effects of WB-EMS on Muscle Strength in Active Young Adult Populations

In summary, seven studies suggest that WB-EMS training can be used to significantly increase muscle strength (5, 6, 7, 10, 11, 19, 26), however, there was only one study (10) that found significant differences compared WB-EMS training with traditional strength training intervention.

The project by Filipovic et al. (7, 8), found that the 14-week WB-EMS intervention significantly improved maximal leg press strength and vertical jump performance and no improvements were found in the jump training control group. In the same line, Ludwig et al. (20) showed that WB-EMS training improves the muscle strength of leg, hip, and trunk to a greater extent than pure athletic strength training. On the contrary, D'Ottavio et al. (6) found all protocols (WB-EMS training and dynamic strength circuit training) significantly improved bench press and squat strength and power to a similar degree; Hussain et al. (11, 12) found in both groups (WB-EMS training and traditional resistance training group) a significant increase in torso rotational strength, and in lower and upper body strength (squat and bench test), and Sadeghipour et al. (25) had similar improvements for maximal strength in both groups (WB-EMS training and strength training group).

In contrast, the project by Hussain et al. (12) showed that the increases in lower and upper body strength for the traditional resistance training group were significantly higher than WB-EMS training group.

Based on the mixture of results, with no significant weight of research pointing to whether WB-EMS training is more, as, or less effective than other training modalities for developing muscle strength in active young adult populations, it is difficult to discern any meaningful conclusions with the current evidence.

Effect of WB-EMS on Anthropometrics in Active Young Adult Populations

Anthropometric results look to be more conclusive than other variables, with both Sadeghipour et al. (25) and Filipovic et al. (8) showing WB-EMS training to be more beneficial to muscle hypertrophy and/or decreasing body fat (%) compared to either a control or training intervention group. From a mechanistic perspective, these adaptations don't seem to be via increased secretion of growth hormone, but potentially via increased muscle damage as Filipovic et al. (7) found no difference between WB-EMS or a jump training control for IGF-1 but did find the WB-EMS had significantly higher levels of creatine kinase (a biomarker of muscle damage). This would suggest, however, that the internal load of WB-EMS training is higher than the jump training, meaning it is difficult to ascertain whether these protocols are similar in creating physiological stress.

Effect of WB-EMS on Performance Variables in Active Young Adult Populations

For endurance variables, such as $\dot{V}O_2$max, ventilatory threshold, running economy, time to exhaustion, La_{max}, aerobic and gas exchange thresholds, mixed results were found. Amaro-Gahete et al. (2) found WB-EMS significantly increased $\dot{V}O_2$max, aerobic and gas exchange thresholds compared to a habitual running control. However, Wirtz et al. (31) contradicted these findings, with their study suggesting that a WB-EMS protocol does not improve $\dot{V}O_2$max, time to exhaustion, or La_{max} compared to jump training or control group. Studies assessing other performance variables also resulted in extremely varied outcomes, with Dörmann et al. (5) finding no significant differences in sprint speed, vertical or horizontal jump performance, or change of direction speed found for the WB-EMS intervention when compared to a strength training protocol. The WB-EMS even resulted in significantly longer ground contact time during drop jump and split time for a change of direction speed. Conversely, Schuhbeck et al. (28), and Hussain et al. (11) found that the WB-EMS group resulted in significant improvements in 10m ice skate time, vertical jump height, and softball batting velocities compared to control groups, although Schuhbeck et al. (2019) found no improvement in ice hockey shot speed.

Study Limitations

Amaro-Gahete et al. (2) had limitations with the small sample sizes used in their studies, with larger sample sizes, the weight of this study would be stronger. Additionally, they did not define what the subjects' habitual running training was. To be able to draw clear conclusions about the efficacy of WB-EMS training, a clear description of the activity of the control group is essential.

D'Ottavio et al. (6) is limited by its unclear procedures. There is no indication as to whether the participants, particularly the control group, ceased their habitual training regimen. The WB-

EMS protocol also wasn't progressively overloaded each session, meaning that the subjects may have got diminishing returns for this protocol compared to the circuit training protocol. Had they implemented a progressively overloaded WB-EMS protocol, the results of this intervention may have been improved.

The study by Dörmann et al. (5) suffered due to its short intervention duration, a 4-week duration is insufficient to show the true effects of an exercise intervention as it does not provide the time needed to notice any discernible differences between groups. The variation and the between-group difference in strength training experience for this study are also concerning (WB-EMS=6.5 ± 3.9 years; Control=3.9 ± 3.2 years) as we know training experience has a significant effect on adaptations to a given stimulus.

Both Filipovic et al. (7) and Filipovic et al. (8), identified inherent limitations in team sports regarding training load. Players were assigned distinct tasks during training based on their positions and also experienced varying playing times during matches. Consequently, complete standardization of the weekly training load was not achievable.

Hussain and Shari (12) produced a relatively robust study, with the only limitation being that the testing procedure slightly favored the resistance training group as exercises used in their training (bench press and squat) were also used as the exercises to test lower and upper body strength. Whilst the WB-EMS did do similar exercises (isometric bench press and squat), they would not have accrued the same neuromuscular adaptations for these exercises as the resistance training group, slightly biasing the results in favor of the resistance training group.

Sadeghipour et al. (25) and Ludwig et al. (20) were both limited by the rep range, external loads, and rest period between sets not being optimal for increasing muscle strength in the strength training group (Schoenfeld et al., 27). Utilizing higher loads augments a change in muscle fiber preference and action potential firing patterns to elicit a faster rate of force development compared to lower loads with higher repetitions. Ludwig et al. (20) also had an extreme variance in results for the WB-EMS group, indicating that whilst on average, WB-EMS training elicits a positive adaptation to exercise, there is a huge variation in responders vs non-responders to the protocol is seen. It also could mean that the intervention strategy was not as tightly controlled as the control group.

Schuhbeck et al. (28) was the only study in this review to use subjects of varying competitive statuses, however, they did not analyze the effects of the protocols between statuses. This would have provided an interesting insight as to how WB-EMS adaptations are affected as the weekly training load is increased.

The study by Wirtz et al. (31) was limited by the low intervention training volume. The study stated that participants undertook a total of 270 minutes per week of football training. It is unlikely that a 20-minute training intervention of WB-EMS or jump training per week will have enough volume per week to elicit any observable results when this equates to around 7% of the total weekly training time.

Review Limitations

One of the key limitations of the studies analyzed in this review is that most of the WB-EMS protocols used in the literature, in terms of electrical parameters, exercise selection, and training volume are based upon landmark studies (12, 14), which were both studies on inactive populations with no experience training. It is well established within the literature that inactive populations have a significantly greater dose response to resistance training than experienced lifters due to the neural adaptations (7, 25). In these populations, the minimum effective dose to elicit an adaptation is significantly less than in trained individuals, so utilizing the same dosage for both populations may not see a realistic response.

It is also worth noting that many of the studies included in this review did not use an equivalent comparison group. Some studies compared the WB-EMS training to a non-training control group or to an intervention group that used the same exercises without WB-EMS. Whilst these studies are useful in displaying a proof of concept that WB-EMS does elicit training adaptations in trained individuals, they do not help provide any conclusions about how effective they are compared to traditional exercise modalities.

It has also been suggested that, due to the novelty of this exercise methodology, the most important electrical parameters for controlling training load have not been established (2). A consensus on the procedure for WB-EMS parameters needs to be established to allow cross-referencing between studies, as well as being able to implement a comparable intervention strategy to compare against the WB-EMS intervention in terms of internal training load and physiological stress. In many of these studies, participants were well trained but had not experienced WB-EMS training before and the studies only lasted a short period of time (most being 4-8 weeks long). It is difficult to discern how much of the adaptations to training are due to the WB-EMS training being a novel stimulus, studies need to use participants who have significant experience using WB-EMS training, and/or longer intervention protocols with regular testing to see if adaptations diminish over time.

Conclusion

To conclude, eleven studies found WB-EMS training does elicit positive adaptations to muscle strength and size, reduce body fat%, increase endurance performance, and improve performance outcomes compared to a non-training control group. However, when compared to other training methods, it does not seem to offer any benefits. More consistency in WB-EMS training protocols, as well as appropriate control groups, is needed for future research. Furthermore, guidelines for WB-EMS training regarding when and how much should be implemented in a training program to elicit the most effective response should be established for practitioners to follow.

Conflict of Interest
The authors have no conflict of interest.

Summary Box

The results on whole-body electromyostimulation (WB-EMS) in more sedentary populations suggest that WB-EMS is a viable alternative to other training methods.

The aim of this study was to provide a systematic review of the existing research on WB-EMS training in relation to muscle strength, anthropometrics and performance variables in active young adults.

This study suggests that WB-EMS does not provide superior training adaptations compared to other training methods in active populations, so clear guidelines for the most effective practices for WB-EMS need to be established.

Table 1

Study characteristics included in the systematic review.

AUTHORS	STUDY-DESIGN	SAMPLE SIZE (EG/CG)	STATUS	SEX, AGE (MV±SD)	CONTROL GROUP	INTERVENTION	MAIN OUTCOMES
Amaro-Gahete et al. (2018)	RCT	12 EG 6 TG 6	Male recreational runners	12 M EG (27.0±7.5) CG (27.0± 6.1)	Male recreational runners	1 sessión/week, 6 weeks	EG: improve in %max, aerobic and gas exchange thresholds, and vertical jump height (countermovement jump and abakalov jump). No significant changes were observed in the CG
D'Ottavio et al. (2019)	RCT	22 EG 6 EG 8 CG 8	Active participants (students of Physical Education)	13 M (25.2±2.8) 9 F (28.2±3.5)	Active participants (students of Physical Education)	2 session/week, 6 weeks	EG: significant improve, but no differences found between groups in bench press and squat strength
Dormann et al. (2019)	RCT	22 EG 11 CG 11	Physically active females	22 M EG (20.4±2.8) CG (20.5±1.8)	Physically active females	2 session/week, 4 weeks	No significant differences found between groups for maximum strength or power for the leg press, leg extension, and leg curl, change of direction speed, straight sprint speed, vertical or horizontal jumps.
Filipovic et al. (2016)	RCT	22 EG 12 CG 10	Elite male players	22 M 12 EG (24.9±3.6) 10 TG (26.4±3.2)	Elite soccer players	2 session/week, 14 weeks	EG: significant improve maximal leg press strength, linear sprinting, change of direction speed, vertical jump performance, and kicking velocity.
Filipovic et al. (2019)	RCT	28 EG 10 TG 10 CG 8	Soccer players	28 M	Soccer players	2 session/week, 7 weeks	EG: significant increase in maximal strength(leg press and leg curl). EG: small increase in diameter of type II myofibers
Hussain et al. (2019)	RCT	40 EG 20 CG 20	Female collegiate softball players	40 F	Female collegiate softball players	3 session/week, 8 weeks	EG: significant increase in muscular strength (torso rotational, batting velocity, bench press and squat)
Hussain et al. (2021)	RCT	60 EG 20 TG 20 CG 20	Female collegiate softball players	60 F (23.52±1.89)	Female collegiate softball players	3 session/week, 8 weeks	EG and TG: significant increase in upper body and lower body strength
Sadeghipour et al. (2021)	RCT	30 EG 10 TG 10 CG 10	Trained women	30 F (25.70±2.27)	Trained women	2 session/week, 6 weeks	No significant differences in body composition and maximal strength
Schuhbeck et al. (2019)	RCT	30 EG 15 CG 15	Amateur male ice hockey players	30 M (27.5±7.9)	Amateur male ice hockey players	1 sessión /week, 12 weeks	There is a greater potential for improvement for hobby sportsmen
Wirtz et al. (2020)	RCT	28 EG 10 TG 10 CG 8	Amateur soccer players	28 M EG (24.4±4.2) TG (21.1±1.9) CG (23.6±3.9)	Amateur soccer players	2 session/week, 7 weeks	EG: no differences in the intramuscular density of monocarboxylate-transporter (MCT) and aerobic performance
Ludwig et al. (2020)	No RCT	30 EG 18 CG 12	Elite youth football players	30 M EG (16.3±0.67) CG (16.4±0.90)	Elite youth football players	1 session/week, 10 weeks	EG: significant increase in muscle strength of leg, hip, and trunk

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