REVIEW ARTICLE

A systematic review and meta-analysis quantifying the increase in energy expenditure from electrical stimulations

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Objective: The prevalence of obesity in the United States is around 40%, yet less than 10% of these individuals meet established exercise guidelines. Neuromuscular electrical stimulations may serve as a more palatable alternative to vonluntary exercise. The purpose of this systematic review and meta-analysis was to quantify the increase in energy expenditure resulting from neuromusucular electrical stimulations administered to healthy adults and clinical populations, and to assess its effectiveness as an alternate to traditional exercise.

Design: Systematic review and meta-analysis.

Methods: The research databases of Medline, Scopus, and Web of Science were searched on June 3, 2025 with the following inclusion criteria: 1) written in English, 2) electrical stimulations administered to skeletal muscles without any other exercise, 3) provide an estimate of energy expenditure or oxygen uptake, 4) administered to humans, and 5) also have a resting energy expenditure estimate. A three-level random effects meta-analytic model was computed. The effect sizes used in the present study were raw energy expenditure values in Kcals.

Results: A total of 36 studies met the inclusion criteria which included 72 effect sizes and 491 participants. The mean weighted increase in energy expenditure was 36.04 (95% CI: 21.23, 50.85; p<0.001) Kcals/30 minutes.

Conclusion: Neuromuscular electrical stimulations increase energy expenditure, but the magnitude appears to be much smaller (~40%) than that of walking. Individuals who are overweight may use electrical stimulations as an alternative to voluntary exercise if they are unwilling or incapable of exercising, but it is unlikely to be as effective as voluntary exercise.

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Keywords: ■ calorimetry ■ energy expenditure ■ E-STIM ■ fat loss ■ obesity

INTRODUCTION

The prevalence of obesity among adults in the United States exceeds 40% which is concerning given the numerous comorbidities associated with being overweight/obese.[1] One way to combat obesity is to engage in voluntary exercise, yet less than 20% of the adult population meets established exercise guidelines, and this number is less than 10% for adults classified as being obese.[2] While the reason for low engagement in voluntary exercise is undoubtedly multifaceted, one commonly cited barrier to exercise is a lack of motivation, with individuals desiring to do other activities with their time.[3] Therefore, alternative strategies designed at promoting weight loss for those who are incapable or unwilling to engage in voluntary exercise are warranted. One such strategy involves the use of electrical stimulations, which can even be combined with more preferred activities such as watching television or reading.

The increased energy expenditure during exercise results from skeletal muscle contractions that requires the breakdown of macronutrients to generate ATP. While exercise requires voluntary activation of skeletal muscle via the motor cortex and spinal cord, skeletal muscle can also be activated involuntarily via the use of neuromuscular electrical stimulations. Neuromuscular electrical stimulations use electrodes placed over the surface of the skin to excite and involuntarily activate skeletal muscles of interest as they bypass the brain and spinal cord. Electrical stimulations have numerous health benefits, one of which is an increase in energy expenditure, which, over time, can enhance the effectiveness of exercise at promoting weight loss.[4]

It is beneficial that electrical stimulations have been shown to promote weight loss, but these protocols appear to produce a wide range of results.[4] One reason for this heterogeneity is likely the duration of the interventions, which have ranged from 4 [5] to 54 [6] weeks. Throughout the duration of these interventions, there are numerous potential confounding factors that, despite trying to control for, will likely influence weight loss, such as altered physical activity, diet, and random biological variability.[7] As such, examining the acute increase in energy expenditure may provide a more controlled means of

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gauging the efficacy of electrical stimulations to promote weight loss without the influence of confounding variables. Therefore, the purpose of the present study was to perform a systematic review and meta-analysis to quantify the increase in energy expenditure that results from performing electrical stimulations.

METHODS

The research databases of Medline, Scopus, and Web of Science were searched on June 3, 2025 using the following search: (E-STIM OR NMES OR "electrical stimulations") AND ("energy expenditure" OR "oxygen uptake" OR "oxygen consumption" OR "weight loss" OR calorimetry or "body mass" OR "body fat"). All articles that were published prior to June 3, 2025 were examined for inclusion. No filters or limits were used when performing the initial searches. All articles were then searched by three different authors for manuscripts that met the inclusion criteria which included: 1) must be written in English, 2) involve electrical stimulations administered to skeletal muscles without any other exercise being performed, 3) provide an estimate of energy expenditure or provide oxygen uptake data to estimate it, 4) be administered to at least two humans (case studies and animal studies were excluded), and 5) must have an energy expenditure estimate at rest and during the electrical stimulation protocol. Studies that utilized electrical stimulations in conjunction with passive cycling or aerobic exercise were not included as passive exercise is also associated with an increase in energy expenditure,[8] and this may be less feasible for the general population looking to perform electrical stimulations at home. The titles and abstracts were initially searched by three investigators independently before meeting to discuss obtaining the full articles. The same three investigators then independently scanned the full articles before meeting to determine which articles met the required search criteria. No automation tools were used in the process. The references of these articles were then scanned for additional articles that may have met the inclusion criteria. A flow chart depicting the exclusion of studies is shown in Figure 1. Information regarding the population and electrical stimulation protocols employed are displayed in Table 1 (Supplementary Materials). To assess study quality, two researchers independently scored each study using the Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group that was developed by the National Institute of Health. The results of the study quality assessment are shown in Table 2

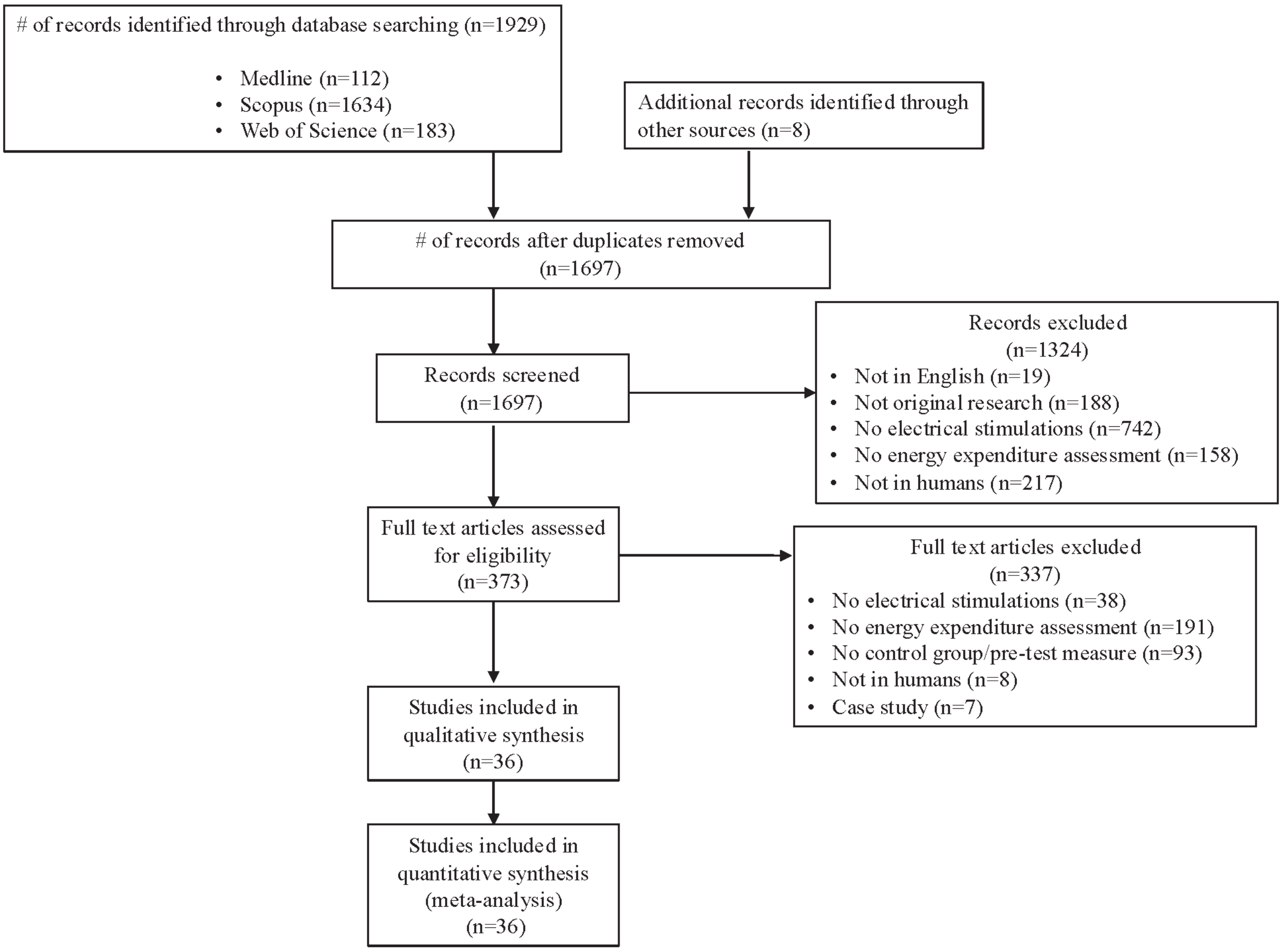

Figure 1. Flow chart detailing search results and exclusion of studies.

(Supplementary Materials). This study was not registered, but no modifications to the review or analysis were made after the initial search for manuscripts.

The effect sizes used in the present study were the raw energy expenditure values in Kcals per 30 minutes (i.e. unstandardized effect sizes). The analysis was computed on the change in energy expenditure from rest to electrical stimulations to determine the additive effect of electrical stimulations above resting energy expenditure. The same author extracted all the energy expenditure data from each of the included studies that was used for the analysis. We elected to use the energy expenditure per 30 minutes as this would adhere to guidelines of achieving 30 minutes of moderate physical activity per day for five days per week.[9] Studies reporting energy expenditure per hour, minute, or day were converted to a 30-minute timeframe. When interquartile ranges were reported,[10] the standard deviation was obtained by taking the average distance of the 25^{th} and 75^{th} percentiles from the median and dividing it by 0.67 which would be the corresponding z score assuming a normal distribution. When standard deviations were reported, they were converted to standard errors using the following formula: $SE = \frac{SD}{\sqrt{n}}$. When 95% confidence intervals were reported, the distance from the mean was divided by the critical t-value associated with the sample size of each study. When energy expenditure values were not reported, but oxygen uptake was, energy expenditure was estimated to be 5kcals for each 1L of oxygen consumed.[11] Each of the studies were weighted for the inverse of the sample variance. We elected to use the standard error of the change score as has been recommended previously.[12] If the change score variability was not reported, it was calculated using the following formula:

$$\mathrm{SD_{intervention}} = \sqrt{[(SD_{Pre\ test})^2 + (\mathrm{SD}_{Post\ test}{}^2) - (2\mathrm{r} \times \mathrm{SD}_{Pre\ test} \times \mathrm{SD}_{Post\ test})]}$$

where 0.9 was used as the estimated correlation (r) between pre-test and post-test values. This r value was chosen based on calculated pre-post correlations from three of the included studies, all of which had r values exceeding 0.9.[13-15] In addition to extracting energy expenditure data, we also extracted participant characteristics (e.g. sex, age, and health status) as well as information on the electrical stimulation protocols employed (e.g. frequency, duration, amplitude, pulse width, and muscles involved).

Statistical Analysis

To account for the dependency of multiple effect sizes nested within individual studies, a three-level random effects (restricted ML) meta-analytic model was computed using the metafor package (version 4.6-0) in RStudio (version: 2025.05.1+513).[16] We did not assess the influence of moderating variables related to the electrical stimulation protocols, as we felt this has already been best addressed in individually controlled studies varying intensities,[13,17,18] frequencies,[19-22] muscle mass involved,[19,23] and duty cycles[23]. A Cochran's Q test was computed to assess heterogeneity and Egger's test was computed to assess the presence of publication bias. As there appeared to be one outlier,[20] a sensitivity analysis was computed removing this study. Statistical significance was set at $p<0.05$.

RESULTS

A total of 36 studies[10,13-15,17-48] met the inclusion criteria which included 72 effect sizes and 491 participants. Included in this sample were 254 healthy adults, 75 individuals with spinal cord injuries, 33 overweight/obese individuals, 37 individuals with septic shock, 30 individuals with chronic obstructive pulmonary disease (COPD), and 62 individuals with type 2 diabetes. The quadriceps were the most stimulated muscle group, often stimulated in conjunction with other muscle groups of the lower body. While there were a large range of electrical stimulation protocols employed, it was most common for studies to set the amplitude to the maximal tolerable intensity (Table 1, Supplementary Materials).

The mean weighted increase in energy expenditure from the electrical stimulation protocols was 36.04 (95% CI: 21.23, 50.85; $p<0.001$; Figure 2) Kcals/30 min with significant heterogeneity in the effect size estimates ($Q=78551.06$; $p<0.001$). When examining sources of variance, 25.0% of the variance could be attributed to within-study variance, and the remaining 75.0% attributed to between study variance. When removing one study[20] that appeared to be an outlier, the estimated energy expenditure was still statistically significant but reduced to 30.07 (95% CI: 20.66, 39.49; $p<0.001$) Kcals/30min. Egger's test was statistically significant ($p<0.001$) suggesting the potential for publication bias with a funnel plot displayed in Figure 3.

DISCUSSION

The primary findings of the present study demonstrate that neuromuscular electrical stimulations can increase energy expenditure by about 36 Kcals/30 min. While modest, this is greater than that of standing (4.5 Kcal/30 min)[49] or fidgeting (20 Kcal/30 minutes)[50]. When compared to voluntary exercise, walking at a speed of 86 meters/min resulted in an increase of 94 Kcals/30 min, and running at 160 meters/min increased energy expenditure by 260 Kcals/30 min.[51] Thus, the estimated increase in energy expenditure resulting from electrical stimulations is likely much less than that of walking, but the magnitude that energy expenditure is increased likely depends on the stimulation protocol used.

Protocols that involve more muscle mass,[19,23] higher stimulation frequencies,[19-22] and higher stimulation amplitudes[13,17,18] will result in greater energy expenditure. Many published studies (see Table 1, Supplementary Materials) employ protocols that require participants to increase the amplitude to the maximal intensity that can be tolerated, but this will likely increase discomfort[52] and reduce the likelihood of long-term adherence. Strategies designed to minimize discomfort such as using larger electrodes[53], or accounting for how individuals cope with dimscomfort[54] may increase the effectiveness of electrical stimulations. While not the purpose of this review, studies have also shown that applying neuromuscular electrical stimulations in conjunction with voluntary exercise such as walking[55] or cycling[56] can enhance the increase in energy

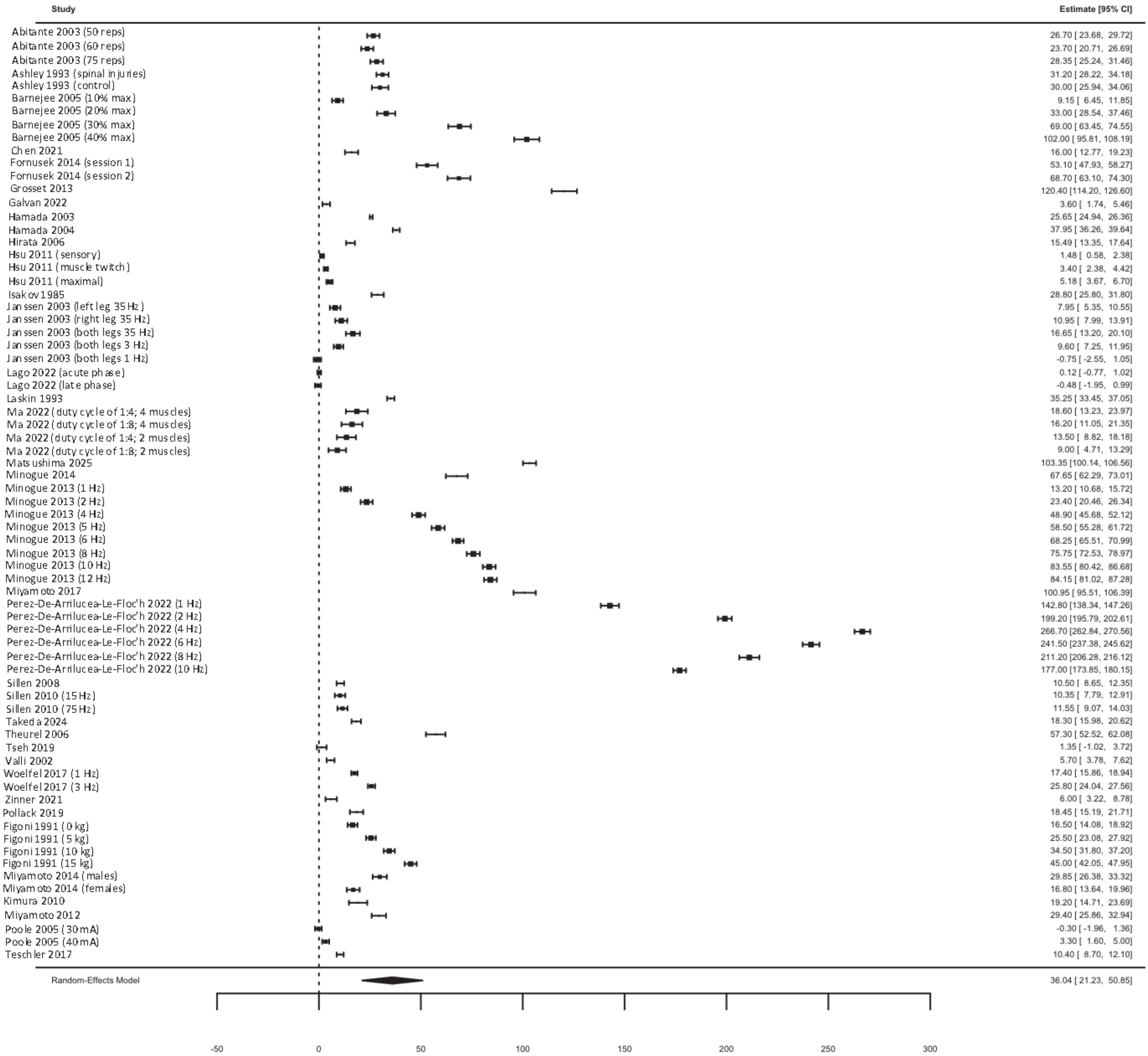

Figure 2. Change in energy expenditure from electrical stimulation protocols. Each study is weighted for the inverse of the sample variance, with larger boxes indicating heavier weights. Effect sizes are non-standardized and indicate Kcals burned per 30 minutes of electrical stimulation. The mean weighted increase in energy expenditure from the electrical stimulation protocols was 36.04 (95% CI: 21.23, 50.85; $p<0.001$) Kcals/30 min with significant heterogeneity in the effect size estimates ($Q=78551.06$; $p<0.001$).

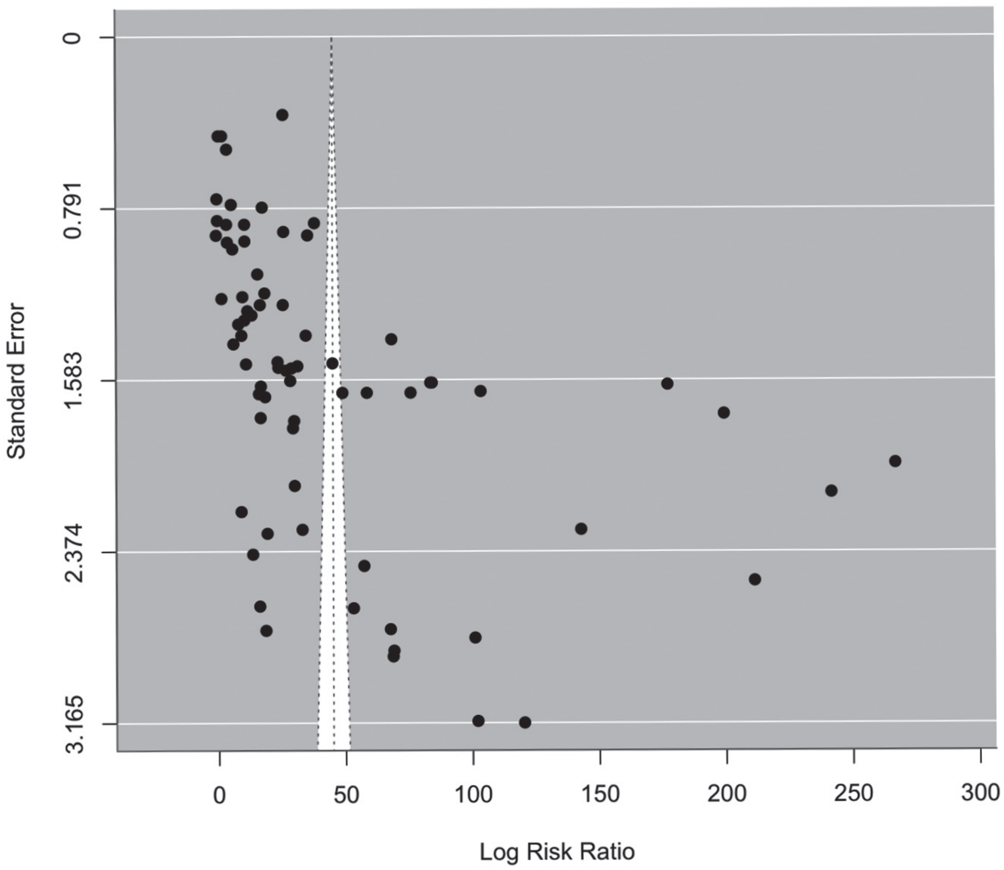

Figure 3. Funnel plot detailing risk of bias. The dotted line indicates the 95% confidence interval and each dot represents an effect size from a single study.

expenditure which may be another utility to promote weight loss. Nonetheless, it seems reasonable to question the feasibility of applying electrical stimulations in conjunction with exercise, however, given the low adherence to exercise in the first place.[2]

In the present study we only accounted for increases in energy expenditure during the electrical stimulation protocol and did not account for excess post-exercise oxygen consumption (EPOC) or increased energy expenditure following exercise. One of the included studies assessed EPOC demonstrating increased oxygen consumption, and thus energy expenditure, for up to 48h post-exercise.[45] While individuals burned an additional 10.4 Kcals/30 min during the exercise, they were still burning an additional 7.4 Kcals, 6.6 Kcals, 5.1 Kcals, 2.6 Kcals, and 0.7 Kcals per 30 minutes at each the 1h, 14h, 24h, 36h, and 48h post-exercise time points, respectively.[45] Therefore, considering that we did not account for the anticipated increase in energy expenditure after completion of electrical stimulations, it is likely that our energy expenditure estimate is slightly underestimated.

Long-term studies assessing whether electrical stimulations can promote reductions in body fat are inconclusive. One meta-anaylsis demonstrated no change in fat mass,[57] while another demonstrated a significant reduction in fat mass resulting from electrical stimulations[4]. This may be due to the larger number of studies included in the more recent meta-analysis. One of these reviews[57] alluded to drastically different results assessing the efficacy of electrical stimulations on changes in fat mass reported by the same research group,[58,59] potentially pointing to the influence of confounding factors over the intervention period. Given our results demonstrating a 36 Kcal/30 minute increase in energy expenditure, individuals performing 150 minutes per week of electrical stimulations could expect to burn 180 Kcals per week. Assuming an energy expenditure of 3,500 Kcals will result in a 1 lb reduction in body mass, this would extrapolate to an estimated 43 weeks of electrical stimulations required to lose 1 kg of body mass. This assumes that energy intake is not altered with electrical stimulations, but we are not aware of any studies assessing ad libitum energy intake following electrical stimulation protocols.

While the reduction in body mass may appear small, it should be mentioned that there are numerous other health benefits that electrical stimulations may confer, even in the absence of weight loss. For example, neuromuscular electrical stimulations can improve gylcemic control and lower fasting blood glucose,[60] which is important given that type 2 diabetes is a common comorbidity for those who are obese. This finding was observed despite the majority of included studies not observing significant changes in body composition.

Therefore, even in the absence of weight loss, electrical stimulations may confer health benefits for indivdiuals who are overweight or obese.

Limitations

One of the primary limitations of the present study is that we could not adequately assess the infleunce of potential moderating variables given the wide heterogeneity of paramaters employed in each study. That is, we could not appropriately assess the influence of body mass, for example, given that the results would be confounded by studies employing different stimulation amplitudes, frequencies, muscle mass involved, etc. We do feel that the influence of numerous confounding factors were best addressed in individually controlled studies as mentioned in the discussion section. Furthermore, we did not account for the influence of EPOC as this was not measured in the majority of studies. Nonetheless, we would expect the overall EPOC to be small in comparison to the oxygen consumption during the electrical stimulation protocol.

CONCLUSION

Neuromuscular electrical stimulations result in modest increases in energy expenditure. Individuals who are overweight or obese may use electrical stimulations as an alternative to voluntary exercise if they are unwilling or incapable of exercising, but it is unlikely to be as effective as voluntary exercise.

CONFLICTS OF INTEREST

None.

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