Muscle and strength adaptations to pulsed electromagnetic field in young women: a pilot intra-individual study

Adaptaciones musculares y de fuerza al campo electromagnético pulsado en mujeres jóvenes: un estudio piloto intraindividual

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Abstract

Introduction: Pulsed electromagnetic field (PEMF) has been proposed as a non-invasive tool to promote muscle adaptations such as strength gains (1RM) and increased muscle thickness (MT). However, the effects of PEMF on lower-limb muscles in young untrained individuals remain underexplored.
Methods: We investigated the effects of an eight-week PEMF intervention on rectus femoris (RF) MT and 1RM in 5 sedentary women. Each participant had one leg randomized to PEMF and the contralateral leg to traditional resistance training on a leg extension machine (EXT). The PEMF protocol consisted of 30-minute (3x/week), at a frequency of 50Hz-3.5 Teslas. The EXT protocol involved 3sets of 8–12reps at ~70%1RM. MT was measured at RF 30% and 50% of thigh length via ultrasonography, and 1RM was assessed bilaterally. Perceived exertion (RPE) was recorded after each session.
Results: PEMF: mean RFMT increased from 1.88±0.23cm to 1.92±0.19cm at 30% thigh length and from 1.79±0.19cm to 1.84±0.13cm at 50% thigh length. EXT: RFMT increased from 1.88±0.14cm to 2.01±0.18cm at 30% and from 1.70±0.33cm to 1.88±0.27cm at 50%. 1RM improved from 36.0±4.7kg to 40.4±5.7kg for PEMF and from 36.0±7.5 kg to 46.6±9.1kg for EXT. Mean session RPE was 3.0±0.9 for PEMF and 8.0±1.0 for EXT.
Discussion: These preliminary findings highlight the potential of PEMF as a low-exertion alternative and provide key parameters for designing a future definitive trial
Conclusion: Both interventions led to improvements in 1RM, while changes in MT were modest and more variable. The PEMF sessions were consistently well tolerated and RPE as requiring low effort.

Keywords

Hypertrophy; muscle thickness; PEMF; resistance training; strength.

Resumen

Introducción: La terapia con campo electromagnético pulsado (PEMF) se ha propuesto como una herramienta no invasiva para promover adaptaciones musculares, tales como incrementos de fuerza máxima (1RM) y aumento del grosor muscular (MT). Sin embargo, los efectos de la PEMF sobre la musculatura de las extremidades inferiores en individuos jóvenes no entrenados siguen siendo poco explorados.
Métodos: Se investigaron los efectos de una intervención de PEMF de ocho semanas sobre el MT del recto femoral (RF) y el 1RM en 5 mujeres sedentarias. Cada participante tuvo una pierna aleatorizada a PEMF y la pierna contralateral a entrenamiento de resistencia tradicional en una máquina de extensión de rodilla (EXT). El protocolo de PEMF consistió en sesiones de 30 minutos (3x/semana), a una frecuencia de 50 Hz y una intensidad de 3,5 teslas. El protocolo de EXT incluyó 3 series de 8–12 repeticiones al ~70%1RM. El MT se midió en el RF al 30% y 50% de la longitud del muslo mediante ecografía, y el 1RM se evaluó bilateralmente. La percepción del esfuerzo (RPE) se registró después de cada sesión.
Resultados: PEMF: el MT medio del RF aumentó de 1,88±0,23cm a 1,92±0,19cm al 30% de la longitud del muslo, y de 1,79±0,19cm a 1,84±0,13cm al 50%. EXT: el MT del RF aumentó de 1,88±0,14cm a 2,01±0,18cm al 30% y de 1,70±0,33cm a 1,88±0,27 cm al 50%. El 1RM mejoró de 36,0±4,7kg a 40,4±5,7kg para PEMF, y de 36,0±7,5kg a 46,6±9,1kg para EXT. La RPE media de cada sesión fue de 3,0±0,9 para PEMF y 8,0±1,0 para EXT.
Discusión: Estos hallazgos destacan el potencial de la PEMF como una alternativa de baja exigencia y aportan parámetros clave para el diseño de un ensayo definitivo futuro.
Conclusión: Ambas intervenciones mejoraron el 1RM, mientras que los cambios en el MT fueron modestos y más variables. Las sesiones de PEMF fueron constantemente bien toleradas y percibidas como de bajo esfuerzo.

Palabras clave

Entrenamiento de resistencia; fuerza; grosor muscular; hipertrofia; PEMF.

Introduction

The pulsed electromagnetic field (PEMF) is a technology used in the field of bone and muscle rehabilitation (Flatscher et al., 2023; Kull et al., 2025). Its ability to trigger physiological responses at the cellular level, inducing pathways such as PGC-1α, mTOR (mammalian target of rapamycin), increased calcium (Ca^{2+}) influx in muscle tissue, and inhibition of negative regulatory proteins such as myostatin and FOXO1 (Leonardo, Cardoso, Vieira, et al., 2023; Maiullari et al., 2023; Pall, 2013; Yang et al., 2018), appears to represents the biological framework explaining how PEMF promotes such adaptations. As a therapeutic intervention, robust systematic reviews validate its efficacy and safety (Kull et al., 2025); however, other applications are being explored regarding the use of this technology (Kinney & Lozanova, 2019).

Recent studies have demonstrated the potential of PEMF in modulating muscle hypertrophy and reducing localized fat, with an emphasis on specific regions such as the abdominal and gluteal areas, aimed even at aesthetic purposes (DiBernardo et al., 2023; Jacob & Paskova, 2018). Supporting the expansion of its application, a recent study showed that 12 weeks of PEMF therapy resulted in improvements in mobility scores, performance in strength tests, and body composition in older adults (Venugobal et al., 2023). Similar results have also been reported in populations with sarcopenia (Leonardo, Cardoso, Oliveira Silva, et al., 2023; Leonardo et al., 2025). Furthermore, a recent review highlighted the potential of using PEMF as a complementary tool to resistance training (Ghanbari Ghoshchi et al., 2024).

The combined use of PEMF with exercise has been investigated for outcomes such as post-exercise muscle recovery, acute reduction of blood pressure, and improved muscle oxygenation (Ghanbari Ghoshchi et al., 2024; Trofè et al., 2021). Chronically, functional gains in strength and muscle performance are evidenced in patients with comorbidities and joint limitations (Parhampour et al., 2014). Reductions in pain levels and increases in strength have also been observed in individuals with subacromial impingement syndrome (Kandemir et al., 2024).

In this context, the present study is structured as a pilot study, following the conceptual framework proposed by Eldridge et al., (2016), which defines pilot studies as a subset of feasibility studies conducted to assess whether and how a future trial can be successfully implemented. Specifically, this investigation aims to generate preliminary data on physiological responses (muscle thickness and strength), protocol tolerability, and intra-individual variability in response to PEMF, thereby informing the design of a future randomized controlled trial with broader scope and statistical power (Eldridge et al., 2016). As highlighted, pilot studies can fulfill scientific purposes by testing recruitment strategies, intervention parameters, and measurement procedures, dimensions that are directly addressed herein.

Despite this growing body of evidence demonstrating that PEMF can induce adaptations like those observed with resistance training (Leonardo et al., 2025), such as increased muscle thickness (MT) and strength performance, the use of PEMF still tends to focus on clinical populations or specific muscle areas, limiting the extrapolation of results to the muscle tissues of the lower limbs in young and healthy individuals. Considering this, the present study aimed to investigate the effects of eight weeks of PEMF application on the MT of the rectus femoris (RF) in the proximal (RF30%) and mid (RF50%) regions in untrained women. An intra-individual analysis model was adopted, in which one leg was randomized to receive the PEMF intervention, while the contralateral leg underwent traditional resistance training on the leg extension machine (EXT), serving as a parallel positive control. Additionally, responders and non-responders were also identified. Secondarily, we analyzed changes in maximum strength performance (1RM), as well as the rating perceived exertion (RPE). It was anticipated that both PEMF and EXT would promote measurable improvements in RF MT (at 30% and 50% of thigh length) and 1RM, with adaptations occurring in the same direction across these outcomes. Additionally, it was expected that RPE would be lower during PEMF sessions compared with traditional resistance training.

Method

Study design and Approach

This investigation was designed and conducted as a pilot study, following the conceptual framework outlined by Eldridge et al. (2016), in which pilot studies are considered a subset study undertaken in preparation for a future definitive randomized controlled trial (RCT). In this context, the primary aim was not to determine definitive efficacy, but to generate preliminary data to inform the design of a larger trial. Specifically, the study sought to assess the tolerability and acceptability of the PEMF protocol in untrained young women, evaluate intra-individual variability in physiological responses (muscle thickness and maximal strength), verify the suitability and reproducibility of the measurement tools employed, and identify logistical aspects and resource requirements for scaling up. These outcomes will support sample size estimation, refinement of intervention parameters, and selection of responsive outcome measures for a future adequately powered RCT. The protocol had a total duration of eight weeks, with assessments conducted before and after the intervention to analyze the dependent variables (MT of RF and 1RM of knee extension). The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Research Ethics Committee of the Evangelical University of Goiás (nº 6.210.982). This study took place from August to December 2024.

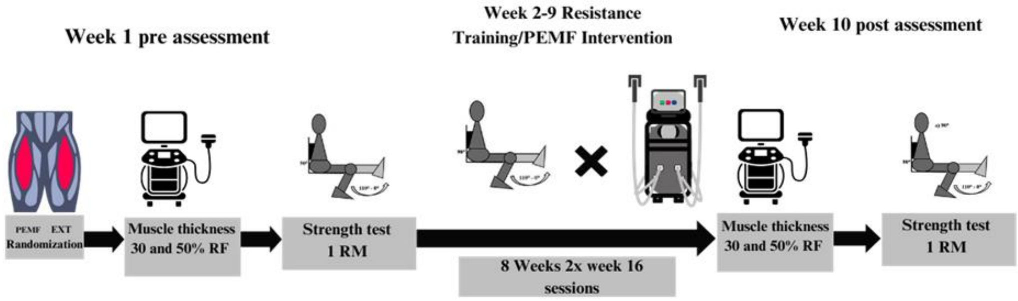
Participants

Five healthy women, with a mean age of 19.6 ± 0.5 years, were recruited to participate in the study. The inclusion criteria included individuals aged between 18 and 25 years who had not been involved in regular resistance training programs in the past six months and who were available to attend the laboratory twice a week during the intervention period. Participants with a history of previous musculoskeletal injuries in the hip, knee, or ankle, as well as those using ergogenic supplements, medications that altered cardiovascular profiles, or those with a history of smoking or chronic alcohol consumption, were excluded. Recruitment of volunteers was conducted through direct approaches and advertising in a gym located within a university in the Midwest of Brazil. During the recruitment period, candidates underwent an initial screening, and if they met the established criteria, they were provided with detailed information about the study procedures before signing the Informed Consent Term.

Randomization, Allocation, and Experimental Development Process

After inclusion in the study, randomization of the legs was performed, using a simple draw to determine which limb would undergo PEMF and which would perform traditional resistance training on the leg extension machine. As an additional control strategy, participants were asked which leg they would use to kick a soccer ball, allowing the identification of the dominant leg. This criterion was adopted to avoid potential influences of lateral dominance on the results. The intervention lasted a total of ten weeks, with the first week designated for baseline data collection and the last reserved for re-evaluation of the dependent variables. Ultrasound images of the RF muscle, as well as a 1RM test on the leg extension machine, were assessed. The experimental phase consisted of 16 intervention sessions, conducted twice a week, with a minimum interval of 48 hours between sessions. The workload and RPE were recorded at each intervention session. The study design is represented in Figure 1.

Figure 1. Experimental design of the study



Pulsed Electromagnetic Field (PEMF); Resistance Training (EXT); RF (Rectus Femoris); Source: Author's own

PEMF Intervention

A portable pulsed electromagnetic field device (Supramaximus Adoxy™, Votorantim, SP, Brazil) was used, consisting of four extendable handles. The device offers specific adjustments for magnetic flux density (tesla), frequency (Hz), and stimulation time (seconds). The stimuli generated by the equipment were applied in two alternating conditions: submaximal, with pulses spaced less than one second apart; and supramaximal or tetanic, which involved sustained contractions. The device has a maximum capacity of 7.0 teslas per handle. During the intervention, participants remained seated, with the handles positioned over the anterior region of the selected thigh, covering the RF (concave handle) in the most proximal portion to the hip. In the initial sessions, the magnetic flux density was set between 20 and 25% of the device's maximum capacity, with a total time of 30 minutes per session. As the intervention progressed, intensity levels were gradually increased, reaching 30 to 35% in the second session, 40 to 45% in the third, and 50 to 55% in the fourth session. This progression pattern was maintained until the ninth session, when the flux density reached 100% of the device's capacity, and this intensity was maintained until the protocol's conclusion. The application of PEMF was conducted in two alternating conditions throughout the sessions. The submaximal condition followed a pattern of pulses with a frequency of 4 Hz, for periods of 10 seconds, while the supramaximal condition consisted of sustained tetanic contractions, with stimuli at 40 Hz for periods of 4 seconds. These parameters were kept constant across all sessions to ensure standardization of the intervention.

Resistance Training Protocol (EXT)

The contralateral leg to PEMF underwent a traditional unilateral knee extension protocol on the leg extension machine (Lion Fitness®), serving as a parallel control. Training occurred concurrently with the PEMF intervention, conducted twice a week on alternate days from the PEMF sessions. Each session consisted of three sets of EXT, using a load corresponding to a range of 8 to 12 maximum repetitions, with a one-minute rest between sets. Before initiating the protocol, each participant performed a specific warm-up on the leg extension machine, executing 8 to 10 repetitions with 40-50% of their maximum load, followed by a one-minute rest. If a participant was able to perform more than 12 repetitions, the load was increased in the next set by increments of 1 to 2 kg, using additional plates attached externally to the machine's weight stack. Conversely, if the minimum of 8 repetitions was not achieved, the load was reduced. The movement was performed to concentric failure, with a standardized cadence of 1 to 2 seconds during the concentric phase and 2 seconds during the eccentric phase, with no pauses between transitions. During training, participants were verbally encouraged but received no external assistance with the execution of the movements. All sessions were supervised by a qualified professional in Physical Education, who did not have access to the initial or final test results, ensuring impartiality in monitoring. Participants were instructed not to perform any other lower limb exercises, being free only for upper limb conditioning. A training program was standardized by a specialized team, including the main multijoint groupings for the segment (bench press, elbow extension, dumbbell shoulder press, high pulley lat pulldown, seated cable row).

Volume Load for EXT

The total training volume for knee extension was monitored and calculated using the equation load × repetitions (Nunes et al., 2021), considering the three sets performed per session, resulting in a total of six sets per week. According to the literature, this workload is considered the minimum necessary to induce hypertrophic adaptations in untrained individuals (Kraemer et al., 2002; Schoenfeld, 2010). It is important to note that volume load was calculated exclusively for the EXT intervention, as the PEMF protocol does not involve external resistance, muscular contractions, or repetition-based activity. Consequently, it is not possible to quantify training volume in conventional terms (e.g., sets × repetitions × load) for PEMF. Therefore, comparisons of volume load between interventions were not conducted.

Procedures 1RM

The 1RM test was conducted before and after the intervention to assess maximum strength gains. Participants underwent a series of warm-ups and progressive attempts, following a standardized protocol that involved: a) specific joint mobility exercises for the knee joint; b) warming up with light loads (approximately 50% of the initial estimate), followed by an attempt with 75% of the estimated load; c) the first attempt to obtain the maximum possible load for a single repetition. If the maximum load could not be achieved, a rest period of three to five minutes was given before a new attempt. The 1RM test occurred over two different visits. In the first visit, a leg was selected and tested randomly. Subsequently, the contralateral leg was also tested after a 48-hour interval.

Ultrasound Measurements

The thickness of the rectus femoris muscle was measured before and after the intervention using B-mode ultrasonography (Mindray M6) coupled with a linear probe L14-6Ns, with a frequency adjustable between 6 and 14 MHz. Measurements were taken at two points on the thigh, corresponding to 30% and 50% of the femur length, using the greater trochanter and the lateral epicondyle of the femur as anatomical landmarks. A single evaluator to ensure standardization of measurements captured images. The reliability of this evaluator's measurements was established previously (Martin Bjørn Stausholm et al., 2024). During the assessment, participants remained at rest for 10 minutes in a supine position, with the environment acclimatized to 21°C. To avoid interference, a layer of aqueous gel was applied to the skin and the probe tip, minimizing compressions that could compromise measurement accuracy.

Rate Perceived Exertion (RPE)

Prior to the intervention period, all participants underwent a standardized familiarization session with the Borg Category-Ratio Scale (CR-10) for perceived exertion. During this session, detailed explanations and practical examples were provided to ensure consistent understanding and accurate self-reporting across participants. At the end of each training session, both knee extension and the PEMF intervention, participants reported their RPE regarding the activity (session RPE). An adapted Borg scale of 0-10 was used (van der Zwaard et al., 2023), as produced and described by Borg, where “0” refers to the perception of exertion as 'extremely light', up to “total fatigue” at 10.

Data analysis

Given the pilot nature of this study, the statistical analysis was descriptive and exploratory, with no formal hypothesis testing. The primary aim was to estimate variability, effect sizes, and confidence intervals to inform the design of a future definitive randomized controlled trial. Continuous variables are presented as mean ± standard deviation (SD) and 95% confidence intervals (95% CI). Relative changes from baseline were expressed as percentage differences (Δ%). For additional insight into response heterogeneity, the coefficient of variation (CV%) and the proportion of participants showing improvement (“responders”) were calculated for each outcome. Between-condition comparisons and within-condition pre–post changes are reported as estimated mean differences with 95% CIs and standardized effect sizes (Cohen’s d) for paired data. All analyses were performed using SPSS version 27.0 for Windows® (Chicago, IL, USA).

Results

Data Normality

For the primary outcome measure, MT of the RF at 30%, normality was observed for the pre-condition (p = 0.485) and post-condition (p = 0.995) in the PEMF, as well as for the pre-condition (p = 0.256) and post-condition (p = 0.960) in the EXT. The same results were found for RF thickness at 50%, with normality in the pre-condition (p = 0.859) and post-condition (p = 0.223) in the PEMF and pre-condition (p = 0.908) and post-condition (p = 0.084) in the EXT. For the 1RM performance, the Shapiro-Wilk test indicated normality for the PEMF intervention in the pre-condition (p = 0.168) and post-intervention (p = 0.437). However, this was not the case for the EXT intervention, which showed normality in the post-condition (p = 0.086) but not in the pre-intervention condition (p = 0.037). Finally, normality for RPE was confirmed, with normal distribution observed for both the PEMF (p = 0.314) and EXT (p = 0.119) intervention.

Adherence to Protocol and Dropout

Participants were informed that participation in the study was voluntary, with no obligation to remain in the study. Throughout the intervention, they had free access to the multipurpose training center, where strength tests and EXT training were conducted. Additionally, they received in-person support from a qualified professional actively working in the field of resistance training. In the PEMF protocol, the use of a relatively new device and the low perception of effort or discomfort facilitated adherence throughout the study. However, despite these measures, one volunteer was unable to fully follow the established schedule due to personal issues, missing sessions in both interventions. To ensure completion of the protocol, her sessions were rescheduled so that she could complete the proposed 16 sessions. Furthermore, two other participants ended their participation before the study concluded, completing only 14 sessions during the experimental period.

Adherence to the intervention protocol was high; however, maintaining full participation in the PEMF condition was occasionally challenging due to the monotonous nature of the exercise and the low physical effort required. In contrast, the PEMF sessions were consistently well tolerated, eliciting minimal reports of discomfort, pain, or fatigue. Moreover, the non-invasive nature of PEMF meant that participants did not need to change clothing or shower afterward, reducing the time burden and logistical barriers often associated with traditional resistance training. These practical advantages may enhance participant compliance in a larger-scale trial. The characterization of the sample is presented in Table 1.

Table 1. Sample Characterization

Variable	Mean ± SD	95% CI	CV (%)
Age (years)	19.6 ± 0.5	19.1 – 20.1	2.6
Weight (kg)	55.8 ± 3.8	52.5 – 59.1	6.8
Height (m)	1.66 ± 0.1	1.59 – 1.73	6.0
BMI (kg/m²)	16.3 ± 8.0	7.3 – 25.3	49.1

BMI = Body Mass Index.
Source: Author's own

Primary Outcome

Table 2 summarizes the RF MT at 30% and 50% of thigh length for both PEMF and EXT conditions, presented as mean ± SD, 95% CI, coefficient of variation (CV%), and paired effect size (Cohen's d). In the PEMF condition, at RF30%, 3 out of 5 participants (60%) showed increased muscle thickness, whereas at RF50%, 3 participants (60%) also demonstrated positive changes. Conversely, in the EXT condition, all participants (100%) showed an increase in RF30%, and 4 out of 5 (80%) improved in RF50%. These data highlight greater consistency in hypertrophic responses following EXT, although individual improvements were also observed in the PEMF condition. Figure 2 displays the responders and non-responders to the PEMF and EXT procedures.

Table 2. Measurements of RF thickness at 30% and 50% Following PEMF and EXT Interventions

Conditions	Pre (mean ± SD)	95% CI Pre	CV% Pre	Post (mean ± SD)	95% CI Post	CV% Post	Effect size (d)
PEMF RF30%	1.88 ± 0.23	1.68 – 2.08	12.2	1.92 ± 0.19	1.75 – 2.09	9.9	0.19
PEMF RF50%	1.79 ± 0.19	1.62 – 1.96	10.6	1.84 ± 0.13	1.73 – 1.95	7.1	0.31
EXT RF30%	1.88 ± 0.14	1.76 – 2.00	7.4	2.01 ± 0.18	1.85 – 2.17	9.0	0.81
EXT RF50%	1.70 ± 0.33	1.41 – 1.99	19.4	1.88 ± 0.27	1.64 – 2.12	14.4	0.60

SD = standard deviation; Δ% = percentage change pre- and post-intervention; CI95% = 95% confidence interval; CV% = coefficient of variation
Source: Author's own

Secondary Outcome

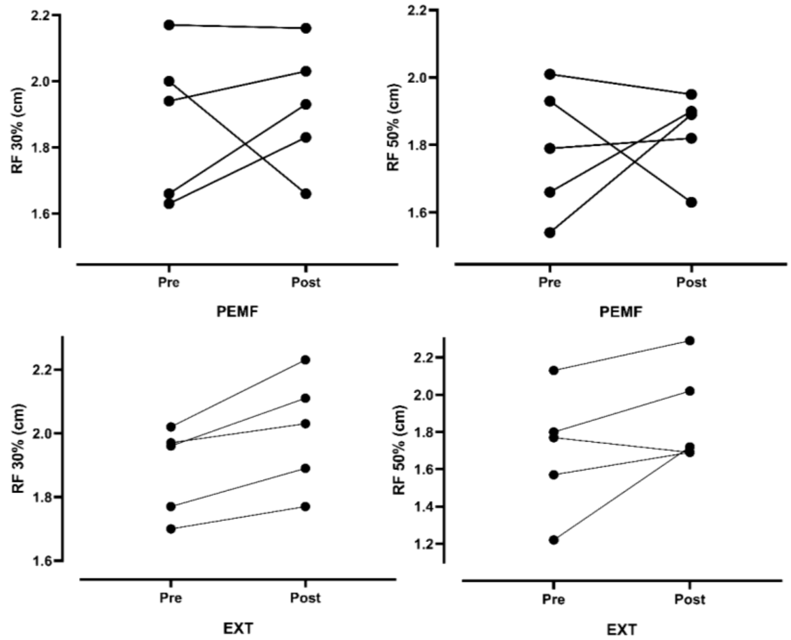
Table 3 presents the variation measures of RM following the PEMF and EXT interventions. All participants improved their 1RM in both conditions, although the magnitude of improvement varied. The observed SDs and CV% values suggest greater variability in the EXT condition, which should be considered when determining the sample size for a definitive trial. Figure 3 displays the total volume load results for each participant in the EXT.

Table 3. Pre- and Post-1RM Measurements

Condition	Pre (mean ± SD)	95% CI Pre	CV% Pre	Post (mean ± SD)	95% CI Post	CV% Post	Relative change (%)	Effect size (d)
PEMF 1RM	36.0 ± 4.7	32.0 – 40.0	13.1	40.4 ± 5.7	35.8 – 45.0	14.1	+12.2	0.79
EXT 1RM	36.0 ± 7.5	29.6 – 42.4	20.8	46.6 ± 9.1	38.8 – 54.4	19.5	+29.0	1.23

SD = standard deviation; Δ% = percentage change pre- and post-intervention; CI95% = 95% confidence interval; CV% = coefficient of variation
Source: Author's own.

Figure 2. Individual changes in RF muscle thickness at 30% and 50% of the thigh length before (Pre) and after (Post) the 8-week intervention period.



Each line represents one participant. The upper panels show the effects of PEMF therapy, while the lower panels display changes following traditional resistance training (EXT).

Figure 3. Individual Volume Load of each participant; the mean of the total individual load multiplied by the mean of the total repetitions.

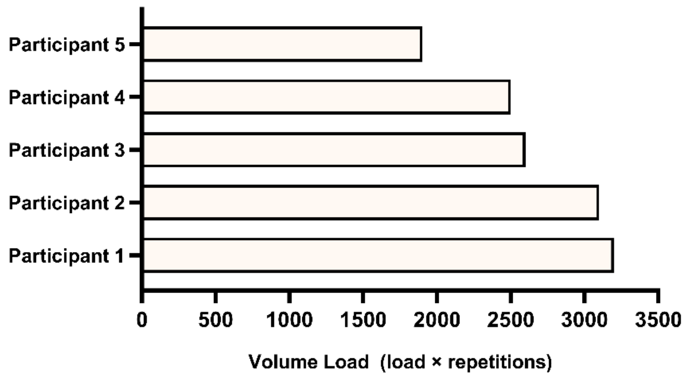
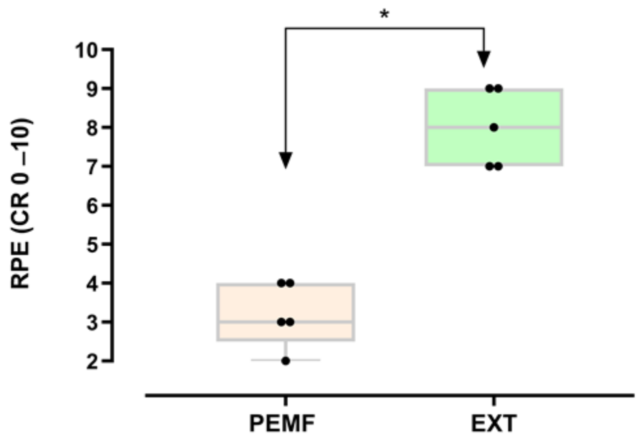


Figure 4 illustrates the session RPE values reported for each intervention. In the PEMF condition, mean RPE was 3.0 (SD = 0.9; 95% CI: 2.1–3.9; CV = 30.0%), whereas in the EXT condition mean RPE was 8.0 (SD = 1.0; 95% CI: 6.7–9.3; CV = 12.5%). This represents a substantial absolute difference of 5 points on the CR-10 scale, corresponding to a very large effect size (Cohen’s d ≈ 5.0). Effect size refers to the magnitude of the difference between PEMF and EXT conditions for RPE values.

The low perceived exertion during PEMF sessions was consistent across participants, indicating high tolerability and minimal discomfort. In contrast, the EXT sessions consistently elicited high RPE scores, reflecting the greater physical demand of traditional resistance training. These differences highlight an important practical advantage of PEMF for populations in which reducing exercise-related effort, fatigue, or discomfort is a priority, and they also suggest potential for improved adherence in larger-scale trials.

Figure 4. RPE of each participant in response to the different interventions.



Discussion

The present study aimed to explore the effects of an eight-week PEMF protocol on RF MT and maximal strength in untrained young women, using traditional resistance training as an active comparator. The findings indicate that PEMF was associated with measurable improvements in 1RM performance, while changes in MT were modest and more variable between participants. The similar direction of adaptation in both interventions suggests that PEMF may serve as an alternative stimulus for strength and MT development, potentially mediated by neuromuscular rather than morphological mechanisms. Additionally, it is important to highlight that the significantly lower RPE observed in the PEMF intervention may enhance adherence, particularly among populations with limitations or contraindications to traditional exercise modalities.

Across all measured outcomes, the pilot data revealed distinct patterns of physiological response, effort perception, and variability that are directly relevant to the design of a definitive trial. The magnitude and consistency of gains in 1RM, coupled with the relatively small and more heterogeneous changes in MT, suggest that strength performance may be a more sensitive short-term indicator of adaptation in this population. The marked contrast in RPE between interventions highlights a potential adherence advantage for PEMF, particularly in contexts where exercise tolerance is a limiting factor. Moreover, the range of coefficients of variation observed across outcomes underscores the importance of accounting for measurement variability when determining sample size and statistical power in the main study. These combined findings provide a multidimensional profile of the interventions' effects, informing both outcome prioritization and methodological refinements for the future trial.

Muscle Thickness Adaptations

As this is a pilot study, our findings should be interpreted with caution. This is the first protocol to investigate the effects of PEMF on the MT of the RF, which limits the extrapolation of the results. Previous studies have investigated the effects of PEMF on the rectus abdominis muscle. For example, Kinney & Lozanova (2019) observed a 15.4% increase in abdominal rectus MT after two months of PEMF application; however, there are significant methodological differences. In the present study, our sample consisted exclusively of young women and an average age of 19.6 years, whereas Kinney & Lozanova (2019) evaluated adults with distinct characteristics who underwent a higher frequency of sessions. Such differences may explain the rejection of our hypothesis, although nearly all participants showed improvement in RF30% and RF50% muscle thickness following the PEMF intervention. Similar results were also reported by (DiBernardo et al., 2023), who demonstrated a 16.2% increase in gluteus maximus thickness after three months of intervention. However, in addition to the analysis being conducted on a different muscle, both Kinney & Lozanova (2019) and DiBernardo et al., (2023) used magnetic resonance imaging (MRI), whereas our protocol was based on one-dimensional ultrasonography measurements in B-mode. Despite the good validity and reproducibility of the ultrasonographic method, it may be less sensitive in detecting subtle morphological changes compared to MRI (Mechelli et al., 2019; M. B. Stausholm et al., 2024).

Regarding the EXT intervention, our findings corroborate existing literature, demonstrating that eight weeks of resistance training with a leg extension machine are sufficient to induce measurable structural morphological adaptations via ultrasonography (Damas et al., 2018; Larsen et al., 2025; Pedrosa et al., 2022). The absence of clear changes in certain measures may relate to methodological considerations similar to those noted for the PEMF intervention. The within-subject design of this pilot minimized the influence of external factors such as diet, sleep, and other intrinsic variables that can affect hypertrophic responses (Hammert et al., 2024), thereby increasing the likelihood that observed variability is attributable to individual.

Another relevant aspect to consider is the low BMI of the participants in this pilot study (mean = 16.3 kg/m^2), which classifies them as underweight according to World Health Organization criteria. This characteristic may have influenced the observed responses, particularly in terms of morphological adaptations. Individuals with lower BMI may present limited muscle mass and altered metabolic or hormonal profiles, which could compromise the hypertrophic response to both PEMF and resistance training interventions (Mithal et al., 2013; Ramsey et al., 2020; Stokes et al., 2018). While strength gains were observed, the absence of significant increases in MT, especially in the PEMF condition, may be partially explained by the participants' baseline body composition. Additionally, reduced levels of leptin and IGF-1 are frequently reported in women with low body weight, which may compromise muscle anabolism (Misra et al., 2003; Roemmich et al., 2003).

Finally, although the effects on MT were not widely observed, the data suggest that protocols with longer duration, adjusted intensity, and larger samples may be necessary to induce more pronounced hypertrophic adaptations with the use of PEMF. Future studies should explore different stimulation parameters and their relationship with potential muscle hypertrophy induction.

Strength Increments of 1RM

Regarding the strength increments assessed through performance in the 1RM test for unilateral knee extension, both interventions promoted positive increases (PEMF: Δ = 12,2%; EXT: Δ = 29%). Our results are pioneering in the evaluation of 1RM performance, in women, in response to the PEMF intervention. Other studies conducted in clinical or elderly populations have shown gains in strength production or maintenance through tests (Leonardo et al., 2025), such as measuring shoulder muscle strength with isokinetic dynamometers and portable dynamometers, assessing isometric strength of lower limbs sustained for 3 seconds (Kandemir et al., 2024; Leonardo, Cardoso, Oliveira Silva, et al., 2023). However, these investigations focused on populations with prior injuries, as well as combining the PEMF intervention with exercises or in elderly populations. This heterogeneity in methodologies limits the comparison of the results obtained in our study with those of another research.

Muscle strength gain, evaluated through 1RM tests, is a common practice in resistance training research, used to assess pre- and post-intervention effects (Schoenfeld et al., 2017). The increase in strength after several weeks of training is widely documented in the literature, reinforced here by the results of the EXT (Del Vecchio et al., 2019). Interestingly, the increases observed in the PEMF suggest that this substantial gain in the intervention may result from improvements in muscle tissue oxygenation and recruitment of motor units (Ghanbari Ghoshchi et al., 2024). PEMF has the potential to directly stimulate peripheral motor nerve fibers, provoking muscle contractions through the depolarization of motor neurons, facilitated by calcium (Ca^{2+}) influx (Pall, 2013). It is important to emphasize that muscle strength adaptations can occur in various contexts, even without inducing significant morphological muscle changes, solely through neural adaptations (Sale, 1988). However, our study did not focus on studying the mechanisms related to such adaptations, which limits our ability to explore these aspects.

Our findings reinforce the potential of PEMF as an innovative tool for enhancing muscle strength in untrained individuals, representing a viable alternative for populations facing barriers to traditional resistance training. However, further studies with larger samples and greater methodological control are necessary to validate and expand these preliminary conclusions.

RPE Responses

It is important to highlight that PEMF induces muscle contractions by directly stimulating peripheral motor nerve fibers, leading to the depolarization of motor neurons and generating pulsatile or tetanic stimuli. Notably, this mechanism occurs without the physical discomfort typically associated with conventional resistance training. Consequently, the significantly lower RPE observed in the PEMF intervention may enhance adherence, particularly among populations with limitations or contraindications to traditional exercise modalities. Lower RPE values are clinically relevant, as perceived exertion is a well-established predictor of exercise adherence, especially in individuals unaccustomed to structured physical activity or presenting with functional limitations or stimuli to which they are not accustomed (Ekkekakis & Lind, 2006; Monturil et al., 2025; Parfitt et al., 2006). In the present study, PEMF was consistently rated as a low-effort activity, suggesting a more tolerable and potentially more sustainable alternative for neuromuscular stimulation. This is particularly important in rehabilitation settings, geriatric care, or among patients with chronic pain or fatigue, for whom high-intensity training may not be feasible. Moreover, the passive nature of PEMF sessions, requiring no voluntary muscle action, may further support adherence by minimizing the psychological and physical barriers often associated with conventional training programs.

What worked and What to improve

Several aspects of the protocol demonstrated feasibility and can be maintained in the larger trial. The PEMF sessions were well tolerated, with consistently low RPE values, minimal reports of discomfort, and logistical convenience, all of which are likely to enhance adherence. The measurement procedures for MT (B-mode ultrasound), 1RM, and RPE proved feasible and reproducible within the laboratory setting.

Nonetheless, certain refinements will be necessary to optimize implementation at scale. Recruitment may require diversification beyond the university setting to achieve the larger sample size, and scheduling flexibility should be increased to accommodate participants' availability. The EXT sessions, while effective, were perceived as painful by some participants, suggesting the need for adjustments in external load or additional engagement strategies to maintain motivation. Furthermore, expanding the monitoring of dietary intake and physical activity outside the protocol could help control for confounding factors. From a methodological standpoint, this pilot highlighted the value of including both morphological and functional outcomes, as their patterns of change may differ in magnitude and variability.

Sample proposition

The variability observed in this pilot study provides essential parameters for estimating sample size in a future definitive trial. For RF30% muscle thickness in the EXT condition, the mean increase was 6.9% (SD = 0.18 cm; 95% CI: 0.01 to 0.35 cm), while in the PEMF condition the mean change was 2.1% (SD = 0.19 cm; 95% CI: -0.09 to 0.33 cm). In terms of 1RM performance, the PEMF intervention elicited a mean improvement of 12.2% (SD = 5.7 kg; 95% CI: 0.45 to 11.8 kg) and the EXT intervention a mean increase of 29.0% (SD = 9.1 kg; 95% CI: 3.4 to 20.6 kg). Using these standard deviations and effect size estimates (Cohen's d ≈ 0.35–0.50 for PEMF vs. EXT on 1RM), a future trial aiming for 80% power at $\alpha = 0.05$ in a two-tailed paired design would require approximately 18–24 participants to detect changes in strength, and 25–30 participants to detect differences in muscle thickness. Such projections underscore the importance of this pilot in informing methodological planning. The identification of responders and non-responders (e.g., 60% improvement rate in PEMF vs. 100% in EXT for RF30%) also suggests that stratified analyses or subgroup considerations may be warranted in the main trial.

Limitations and Future Research

This study, despite its exploratory nature, is a pilot study and, as such, is not without limitations that should be highlighted. Firstly, it is necessary to conduct investigations in a larger population to enhance the robustness of the results. Additionally, controlling for variables such as participants' diet should be considered in future studies to better understand the effects of PEMF on muscle hypertrophy. Our study focused exclusively on a female population, which limits the extrapolation of the results to a male population. Finally, our analysis concentrated on only two sites for measuring MT. Regarding measurement tools, B-mode ultrasound proved practical and reproducible for detecting changes in muscle thickness, though it may be less sensitive than MRI in detecting subtle morphological alterations. The 1RM test and RPE scale were well tolerated and easily implemented, supporting their suitability for inclusion in a larger randomized controlled trial. Future investigations should encompass other muscle areas and measurement sites, allowing for a more comprehensive understanding of the effects of PEMF on muscle hypertrophy.

Conclusions

This pilot study explored the effects of eight weeks of PEMF and traditional resistance training on rectus femoris muscle thickness and maximal strength in untrained young women. Both interventions led to improvements in maximal strength, with the EXT condition producing larger gains, while changes in muscle thickness were modest and more variable. The PEMF sessions were consistently well tolerated and perceived as low-effort, indicating potential advantages for adherence in populations with limited exercise tolerance. These findings, although preliminary, provide valuable estimates of variability, effect sizes, and practical feasibility parameters that will inform sample size calculations, outcome prioritization, and protocol refinements for a future definitive randomized controlled trial.

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