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THE RELATIONSHIP BETWEEN PERCEIVED EFFORT, MUSCLE HYPERTROPHY, AND STRENGTH GAINS: A PILOT STUDY

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ABSTRACT

The present study aimed to analyze the association between ratings of perceived exertion (RPE) and the responses of muscle hypertrophy and maximal dynamic strength after a period of resistance training. For this purpose, ten healthy, untrained adult women underwent 12 weeks of knee extension training, performing 3–6 sets of seven repetitions at 60% of one-repetition maximum (1 RM) with a three-minute rest between sets. At the end of the last set, the RPE (Borg scale: 6-20) was reported. Before and after the training period, the cross-sectional areas (CSA) of the vastus lateralis (VL), vastus intermedius (VI) and rectus femoris muscle (RF) were measured and summed, and maximal dynamic strength was assessed using the 1 RM test. Spearman's correlation coefficient was used to verify the relationship between the percentage changes in individual and summed muscles CSA (CSA_summed), as well as 1 RM performance, and the median RPE reported by participants across the training sessions. The results indicated a weak and non-significant relationship between RPE and hypertrophy of VL (p = -0.050; *p* = 0.892), VI (p = 0.186; *p* = 0.607), and RF (p = 0.235; p = 0.513), as well as the CSA_summed (p = 0.242; p = 0.501). Likewise, no significant correlation was observed between RPE and maximal strength gains (p = 0.025; p = 0.946). Thus, under the present exploratory conditions, no clear association was detected between RPE and hypertrophy or strength outcomes, suggesting that RPE may not be a reliable predictor of chronic adaptations in untrained women.

KEYWORDS

Muscle hypertrophy, perceived effort, resistance exercise, strength, weight training

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INTRODUCTION

Resistance training (RT) consists of a structured organization of exercises capable of producing different adaptations, such as increased muscle strength performance[1]. RT also promotes other adaptations, including increased muscle mass (hypertrophy), bone mineralization, and joint mobility[1]. Beyond these adaptations, RT plays a crucial role in the prevention and management of chronic diseases, including mental illnesses, hypertension, and diabetes, thereby contributing significantly to practitioners' overall health and well-being[2]. Due to its multiple benefits, RT is recommended for a wide range of individuals, from athletes to those undergoing rehabilitation [1]. To achieve these benefits, RT should be organized based on principles involving exercise selection and manipulation of training variables (e.g., number of sets and repetitions), aiming to deliver a training load capable of eliciting both acute and chronic responses[3,4].

Considering acute responses, muscle fatigue resulting from resistance training (RT) has been recognized as a potentially important factor. For instance, evidences suggests that increases in anabolic hormone concentrations (e.g., testosterone)[5] and electromyographic activity (indicative of motor unit recruitment)[6] are associated with neuromuscular fatigue induced by performing repetitions to or near failure. Assuming that increases in anabolic hormone levels and motor unit recruitment are physiological responses associated with muscle hypertrophy[7], it is plausible to speculate that individuals who experience greater fatigue during training may exhibit enhanced hypertrophic adaptations when following a similar training protocol. It is worth noting that individuals with different training backgrounds can perform varying numbers of maximal repetitions at the same relative intensity[8]. Therefore, performing a fixed number of repetitions at a given relative intensity may induce varying levels of fatigue among participants in a resistance training program[9]. Accordingly, the closer this fixed number of repetitions is to an individual's maximum, the greater the effort and resulting neuromuscular fatigue.

Neuromuscular fatigue is a process that leads to a reduction in force-generating capacity and is caused by multiple factors, including the depletion of energy substrates such as glucose and the accumulation of metabolites such as hydrogen ions and inorganic phosphate[10], as well as neural factors[11]. Fatigue levels can be estimated through surface electromyographic (sEMG) frequency analysis during muscle contractions[12,13]. However, this method may not be practical for most coaches due to the high cost of electromyography equipment and the need for signal normalization and analysis. Additionally, the literature highlights limitations in using sEMG frequency analysis in dynamic muscle actions[14]. A valid and simple alternative for estimating muscle fatigue is through rating of perceived exertion (RPE) during training[15,16].

RPE can be measured using a scale ranging from 6 (minimal exertion) to 20 (maximal exertion)[15]. For a better understanding of exertion effects in RT, RPE can be assessed at the end of each training session, allowing for a more accurate interpretation of the physiological impact throughout the session. In RT, RPE provides subjective indicators of fatigue, with higher RPE values being associated with greater blood lactate concentrations and EMG activity[17]. Previous studies also indicate that a greater number of repetitions leads to increased RPE[18,19], and longer repetition duration is linked to higher lactate concentrations[20]. However, the relationship between RPE and muscle hypertrophy remains unclear. Previous evidence has shown that different RPE values for the same trained musculature throughout training sessions resulted in similar hypertrophy and strength gains[21,22]. Nevertheless, the limited number of studies on this topic highlights the need for further research into the direct association between RPE values and hypertrophic responses after a training period.

Another adaptation to RT is the increase in maximal dynamic strength[21]. However, there is a lack of strong evidence supporting a significant and positive relationship between RPE over a training period and increases in maximal strength. A previous study showed that performing fewer repetitions at high intensity elicited higher RPE than more repetitions at low intensity[23]. Thus, the more intense the training, the higher the RPE. However, performing a fixed number of repetitions at a given relative intensity may allow for a varied number of maximal repetitions across individuals[24]. Hence, the closer the training protocol is to failure, the higher the RPE[23], which supports the hypothesis of a potential positive relationship between RPE and increases in maximal dynamic strength. Therefore, the objective of the present study is to investigate the association between RPE values and hypertrophy and strength outcomes after a training period with a fixed number of repetitions and relative intensity.

MATERIALS AND METHODS

Sample

The sample consisted of 10 untrained female university students aged between 18 and 30 years (age = 22.7 ± 2.8 years; body mass = 61.5 ± 9.0 kg; height = 1.61 ± 0.01 m; body fat percentage = 25.9 ± 5.1%). Participants were intentionally restricted to untrained women to reduce variability related to training background.

Ethics approval and Consent to participate

The study was approved by the local ethics committee and followed international research standards.

Experimental Design

The ten women trained on a knee extension machine for 12 weeks using a full range of motion (100° to 30° of knee flexion; 0° = fully extended). The program comprised

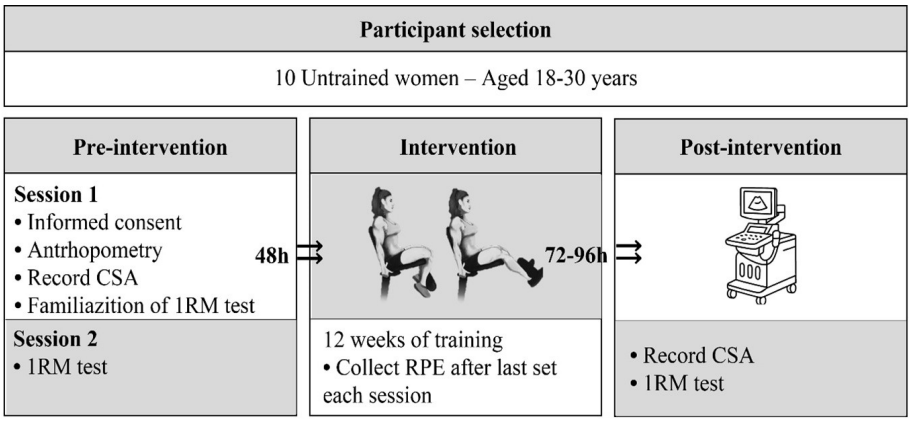


Figure 1. *Experimental design. Abbreviations: CSA, cross-sectional area; 1 RM, one-repetition maximum; RPE, rating of perceived exertion.*

36 sessions (three per week, 48-72 h apart). Training consisted of 3-6 sets of 7 repetitions at 60% of one repetition maximum (1 RM), with 3-min rest intervals. At the end of the final set in each session, RPE was rated using the Borg 6-20 scale, and the median RPE across the 36 sessions was calculated for each participant.

Muscle hypertrophy was assessed by the total change in the cross-sectional area (CSA) of the vastus lateralis (VL), vastus intermedius (VI), and rectus femoris (RF), measured pre- and post-training via B-mode ultrasound. Strength gains were determined by the percentage change in 1 RM on the knee extension machine. Median RPE values were then correlated with hypertrophy and maximal strength gains. *Figure 1* illustrates the experiment design.

Pre-Intervention

Session 1: Participants provided informed consent and underwent anthropometric assessment (height, body mass, and body fat percentage - determined from the sum of seven skinfolds[24]). After a 10-minute rest in the prone position, the anterior region of the right thigh was marked to identify ultrasound acquisition sites for the VL, VI, and RF at 40%, 50%, 60%, and 70% of femur length. Markings were determined using a measuring tape and a laser device for axial alignment *(Fig. 2)*.

Ultrasound imaging was performed using a Mindray® DC - 7 system with a linear array transducer (5 - 10 MHz, 21 frames/s, 7.7 - 9.7 cm depth, 50 - 64 dB gain). Settings were adjusted individually to optimize image quality. A single evaluator acquired two transverse images per site, moving the probe along a line parallel to the femur at constant speed. In total, 64 images were obtained for each participant (32 pre- and 32 post-training).

To reproduce markings post-training, tracing paper overlays from pre-intervention markings were used. Images were exported in DICOM format and analyzed in Horos software (Annapolis, MD, USA). The CSA of each muscle was manually delineated, averaged across the two images per site, and summed across all four regions and between all muscles (CSA_summed) for statistical analysis.

Session 2: Participants were familiarized with the 1 RM testing procedures using the same range of motion adopted during training (100°- 30° of knee flexion). They were positioned on the knee extension machine with 110° of hip flexion and secured with a four-point belt. Familiarization included up to six attempts with 3-min rest intervals[23]. At least one additional attempt with 1 kg above the recorded 1 RM was performed to confirm maximal effort.

Session 3: Forty-eight hours later, the official 1 RM test was conducted using identical procedures. These values were used to determine training intensity (60% of 1 RM) for subsequent sessions.

Intervention

Training began 48 hours after the final pre-intervention session. Participants completed three weekly sessions for 12 weeks. Each session involved 3 sets of 7 repetitions (4 s total duration: 2 s concentric + 2 s eccentric) at 60% of 1 RM, with 3-min rest intervals. The number of sets was progressively increased: 4 sets during weeks 3-5, 5 sets during weeks 6 - 8, and 6 sets during weeks 9 - 12. To maintain relative intensity, 1 RM was reassessed every two weeks immediately before training. RPE was recorded after each session using the Borg 6-20 scale[15]. Participants were instructed to associate higher scores with greater exertion during progressively heavier loads, with 20 representing maximal effort. This familiarization aimed to ensure consistent perception of effort. The median RPE across all sessions was used for subsequent analyses.

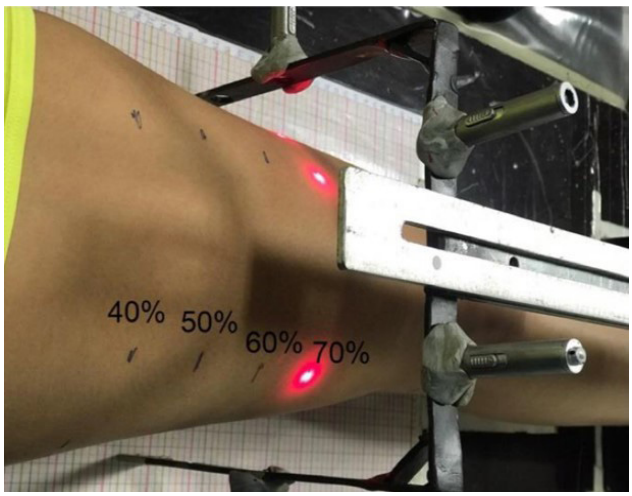


Figure 2. *Laser-assisted marking.*

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Variables	Pre	Post	Change (%)	p value
CSA_summed (cm^2)	92.69 ± 22.44	104.42 ± 24.90	13.29 ± 7.13	<0.001
CSA VL (cm^2)	51.88 ± 11.62	58.25 ± 12.87	12.78 ± 6.86	<0.001
CSA RF (cm^2)	19.63 ± 5.62	22.38 ± 7.25	13.98 ± 6.85	0.003
CSA VI (cm^2)	21.18 ± 5.94	23.68 ± 6.38	13.70 ± 10.01	0.001
1 RM test (kg)	39.28 ± 6.78	45.91 ± 6.62	17.82 ± 8.41	<0.001

Table 1. *Changes in CSA_summed of the VL, VI, and RF muscles, and in the load lifted during the 1 RM test.*

Post-Intervention

Between 72 and 96 hours after the final session, participants repeated the ultrasound and 1 RM assessments using the same baseline procedures. Images of the VI at 40% and 50% femur length were excluded due to insufficient quality; therefore, VI cross-sectional area was calculated from the 60% and 70% sites.

Statistical Analysis

Initially, absolute values of CSA and 1 RM test performance were transformed into relative values: (Post-Pre)/Pre × 100. Then, the median RPE values for each participant throughout all trained sessions were calculated. Next, to confirm whether hypertrophy and strength increases occurred, pre- and post-training values of the summed CSA of each muscle and of the combined CSA (CSA_summed), as well as 1 RM performance, were compared using paired Student's t-tests. Effect sizes (Cohen's d) were calculated (trivial <0.20; small = 0.20 - 0.60; moderate = 0.61 - 1.20; large = 1.21 - 2.0; very large >2.0)[25] and 95% confidence intervals (CI) for the observed increases were also computed. Then, the relative values for changes in each CSA muscles and combined and 1 RM test were associated with the median RPE using Spearman's correlation test. All analyses were conducted using SPSS version 22.0, with statistical significance set at α = 0.05.

RESULTS

According to the t-test, there was a significant increase in the CSA_summed after training ($t(9) = -5,482$, $p < 0.001$, ES = 1.73; 95% CI = 6.89 - 16.58).Considering the analysis of each muscle individually, paired t-tests revealed a significant increase in all of them (VL: t(9) = - 5.985, p <0.001, ES = 1.89, CI = 3.96 - 8.77; RF: t(9) = - 4.144, p = 0.003, ES = 1.31, CI = 1.25 - 4.26; VI: t(9) = -4.531, p = 0.001, ES = 1.43, CI = 1.31 - 3.92). Still according to the t-test, there was a significant increase in strength measured by the 1 RM test (t(9) = -7.765, p <0.001, ES = 2.46, CI = 4.70 – 8.57), corresponding to an increase of 17.82% ± 8.41%. *Table 1* presents the absolute pre- and post-training values of 1 RM and CSA.

Regarding RPE, the quartiles of the dataset were: first quartile = 16.0, second quartile = 17.0, and third quartile = 18. The minimum median RPE value was 14, and the maximum was 19. However, the correlation analysis between the median RPE and the percentage change in the CSA_summed was considered weak, negative, and not statistically significant (p = - 0.219, p = 0.544, 95% CI = - 0.45 to 0.76). Similarly, weak and non-significant correlations were found between RPE and the hypertrophy

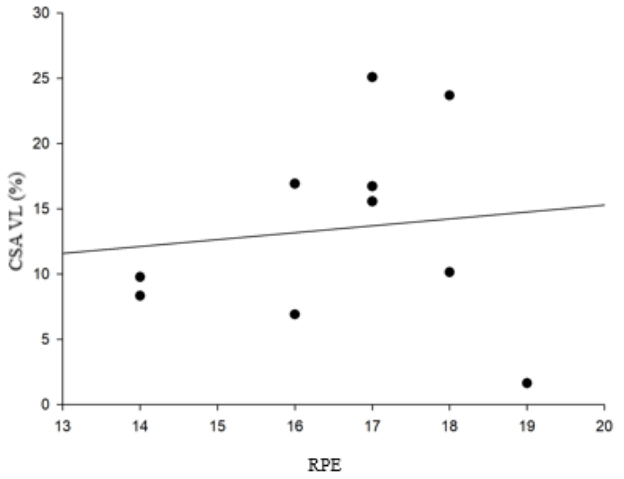


Figure 3. *Correlation between the median RPE and CSA of the VL muscle.*

Abbreviations: RPE, rating of perceived exertion; CSA, cross-sectional area; VL, vastus lateralis.

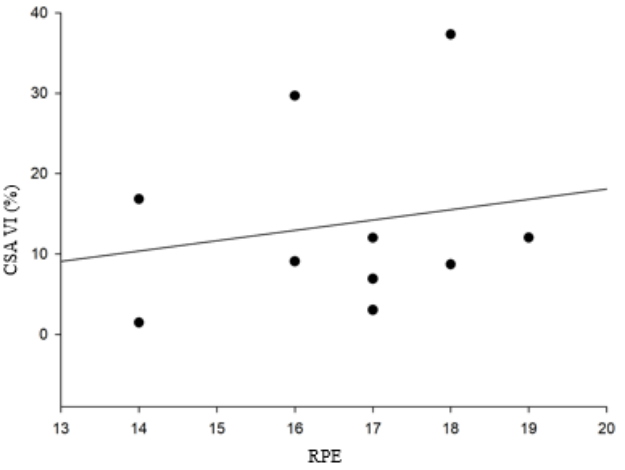


Figure 4. *Correlation between the median RPE and CSA of the VI muscle.*

Abbreviations: RPE, rating of perceived exertion; CSA, cross-sectional area; VI, vastus intermedius.

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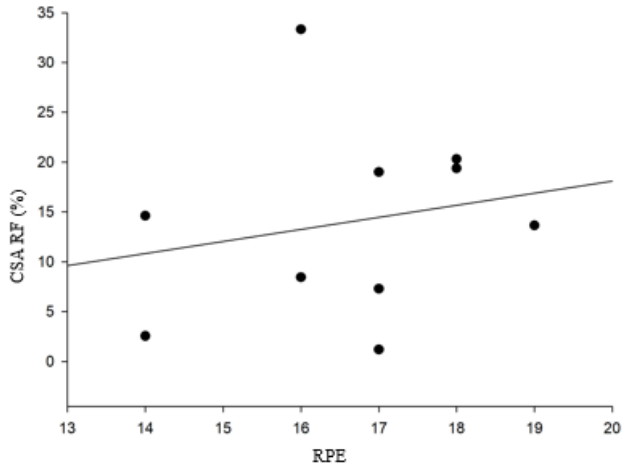


Figure 5. *Correlation between the median RPE and CSA of the RF muscle.*
Abbreviations: RPE, rating of perceived exertion; CSA, cross-sectional area; RF, rectus femoris.

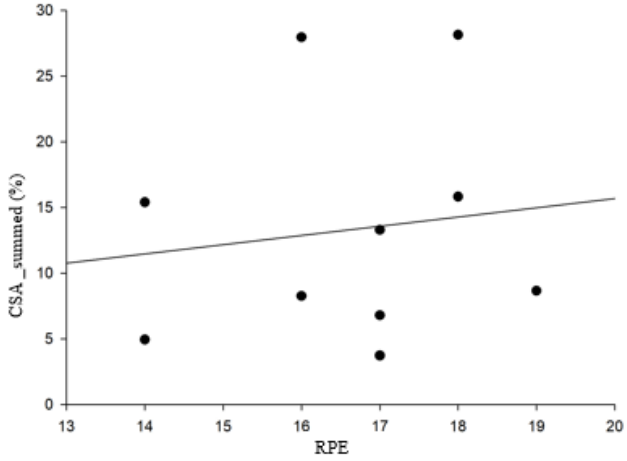


Figure 6. *Correlation between the median RPE and CSA_summed of the muscles.*
Abbreviations: RPE, rating of perceived exertion; CSA, cross-sectional area.

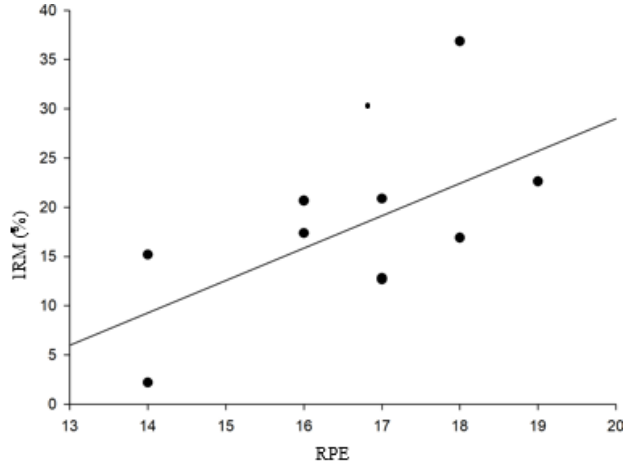


Figure 7. *Correlation between the median RPE and changes in strength observed in the 1RM test.*
Abbreviations: RPE, rating of perceived exertion; 1 RM, one-repetition maximum.

of the VL (p = -0.050, p = 0.892, CI = - 0.54 to 0.70), VI (p = 0.186, p = 0.607, CI = - 0.49 to 0.73), and RF (p = 0.235, p = 0.513, CI = - 0.46 to 0.75), as well as maximal strength gains (p = 0.025, p = 0.946, CI = -0.07 to 0.88). *Figures 3, 4, 5 and 6* illustrate the correlation between these variables. The correlation analysis between the median RPE and the change in strength assessed by the 1 RM test was considered moderate, positive, and not statistically significant (p = 0.578, p = 0.086). *Figure 7* illustrates the correlation between these two variables.

DISCUSSION

The aim of the study was to investigate the association between the median RPE values recorded during the training sessions and the hypertrophic response and increase in muscle strength after a period of strength training on the knee extension machine. Regarding RPE, a median value ranging from 14 to 19 was observed among the participants across the sessions, indicating that the training provided a level of effort considered difficult. However, a weak negative and non-significant correlation was found between RPE and muscle hypertrophy.

Recent evidence from a systematic review and meta-analysis indicates that ratings of perceived exertion show moderate to high convergent validity with physiological markers of exercise intensity during resistance exercise tasks (e.g., heart rate, blood lactate, EMG), supporting RPE as a useful tool for monitoring intensity in acute settings[16]. However, these findings are derived mostly from cross-sectional or acute exercise designs rather than longitudinal adaptations, which may partly explain the weak associations observed in the present study.

The present findings did not provide sufficient evidence to support a positive association between RPE and hypertrophic adaptations under the current experimental conditions. However, given the limited statistical power and restricted between-subject variability, these null associations should be interpreted with caution and cannot be considered indicative of the absence of a physiological effect. In the study by Gomes et al.[26], 20 trained men (>3 years of training) were equally divided into two groups to execute two different training progression protocols over 6 weeks in the Smith squat. In the first group, progression occurred through an increase in the number of sets and weights added every two weeks (2 × 12 - 15 RM; 4 × 8-10 RM; 6 × 4 - 6 RM). The second group followed a progression based on RPE (scale from 0 to 10). This group started training by performing 2 × 12 - 15 RM, and RPE was recorded at the end of each session. When the reported RPE values reached ≤5, the training load was adjusted. Furthermore, when the reported RPE was between 6 and 8, the load was maintained for the next session. However, when the reported RPE was ≥9 for two consecutive sessions; one of the planned sets was skipped in the next session. It is worth mentioning that the number of sets was equalized between the groups throughout the

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weeks. For hypertrophy analysis, the CSA of the VL and RF muscles was measured using ultrasonography before and after training. Both groups showed positive hypertrophic responses; however, no significant differences were found between the groups ($p = 0.32$).

The results from the study above[26] suggest that different training strategies, whether manipulating volume and intensity over a fixed period or using RPE, can produce similar hypertrophic responses. In the present research, since the RPE values varied from 14 to 19 among participants, this variation was not enough to show an association with greater or lesser levels of hypertrophy. Recent evidence indicates that different levels of fatigue may result in similar motor unit recruitment patterns[27], possibly due to a plateau in the sEMG signal amplitude a few repetitions before muscle failure[28]. Accordingly, the reported RPE values showed a relatively narrow distribution. This restricted range likely limited between-subject variability and reduced the ability to detect dose-response relationships between perceived effort and chronic adaptations. Although standardized loading enhances experimental control, it may also constrain individual differences in perceived exertion, thereby limiting the sensitivity of correlational analyses.

In addition to physiological factors, RPE is strongly influenced by cognitive and psychological components, including motivation, expectations, pain tolerance, emotional state, and familiarity with the exercise task[15,23,29]. These factors may vary substantially between individuals, even when training load and volume are standardized. Consequently, similar external workloads may be perceived differently, which may partially explain the weak associations observed between RPE and chronic adaptations in the present study. Therefore, perceived exertion should be interpreted as a multidimensional construct reflecting both physical and psychological responses to exercise.

Muscle growth, among many factors, depends on a positive balance between protein degradation and synthesis resulting from the training stimulus[7]. This synthesis is stimulated by the activation of the Akt-mTOR pathway, which is also sensitized by strength training[7]. Considering the median RPE of the participants ranged from 14 to 19, it is possible that the anabolic stimulus necessary for protein synthesis from the individual training stress was similar among participants. In this case, the differences in RPE during training among participants might not be enough to impact muscle hypertrophy response, leading to a lack of significant association between these two variables.

Regarding muscle strength, a significant increase was identified in this variable, suggesting that the training was effective in increasing maximum strength on the knee extension machine. However, a weak positive and non-significant correlation was found between the median RPE and the increase in muscle strength. To the best of our knowledge, no studies have analyzed RPE in relation to strength gains following the procedures of the present study. On the other hand, previous investigations have used RPE as a tool for prescribing and monitoring training load[29], rather than as an independent variable to analyze its direct association with strength gains. This methodological distinction may explain the lack of conclusive evidence regarding the relationship between RPE and neuromuscular adaptations. Previous studies have shown that different training manipulations, such as variations in intensity, cadence, or prescription method, result in distinct acute physiological and psychological responses, which are reflected in RPE values[24,30-32]. However, these transient responses do not necessarily translate into modulators of long-term adaptations such as hypertrophy or strength gains. This reinforces the importance of interpreting RPE as a comprehensive monitoring indicator throughout the training process, rather than merely as a momentary measure of exertion.

Recent studies have also highlighted the complex relationship between perceived exertion, neuromuscular responses, and performance outcomes. For example, Ceruso et al.[33] reported that changes in perceived effort were accompanied by improvements in strength in adolescents undergoing resistance training. Similarly, Formiglio et al.[34] emphasized that multiple physiological and contextual factors influence performance enhancement and effort perception. In addition, Kale et al.[35] demonstrated that different pre-conditioning intensities may result in distinct performance responses, reinforcing the notion that the relationship between effort perception and physiological adaptation is not necessarily linear. Together, these findings support the interpretation that RPE reflects a multifactorial construct, which may partly explain the weak longitudinal associations observed in the present study.

The present study has limitations. The most critical limitation is the small sample size, which restricts statistical power and generalizability. In addition, the exclusive inclusion of untrained women limits the external validity of the findings, as sex- and training-status-related differences in RPE responses and neuromuscular adaptations have been previously reported[8,17,27]. Therefore, the present results should not be extrapolated to trained individuals or to male populations. Another limitation of the present study is the use of a single-group pre-post design, which restricts internal validity and limits causal inference. Although the inclusion of a comparative group (e.g., training to failure versus submaximal effort) could have provided additional insight into the relationship between perceived exertion and proximity to failure, the present design allowed for a controlled examination of individual responses under standardized training conditions. This approach enhances ecological validity and reflects practical training settings, in which individuals often follow similar programs under supervision. Future studies incorporating comparative designs are warranted to further clarify the role of RPE in

modulating long-term adaptations.

This pilot study did not detect a clear association between median RPE and gains in muscle strength or hypertrophy under the present training conditions. Notably, participants achieved substantial increases in muscle size and strength despite relatively similar perceived exertion levels, suggesting that, when training load and volume are adequately controlled, individual variations in RPE may not strongly influence chronic adaptations in untrained women. However, these findings should be interpreted cautiously, as limited statistical power and restricted variability in perceived exertion may have constrained the detection of potential dose-response relationships. Therefore, the absence of significant correlations should not be interpreted as evidence of the absence of physiological effects. Future investigations with larger and more heterogeneous samples and greater variability in effort levels are needed to clarify the role of RPE in long-term neuromuscular adaptations.

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