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Research Article

# Muscle activity increased after co-contraction resistance training, but it was unrelated to the rating of perceived exertion in older adults

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## HIGHLIGHTS

- We investigated the co-contraction training for lower limbs in older adults.
- There was no correlation between RPE and EMG activity in co-contraction and conventional resistance training.
- EMG activity in the co-contraction training was lower than conventional training.
- EMG activity increased after a period of co-contraction training.

## ABBREVIATIONS

| | |
|---|---|
| BF | Biceps femoris long head |
| CCT | Co-contraction training |
| CRT | Conventional resistance training |
| EMG | Electromyographic |
| HR | Heart rate |
| MVIC | Maximal Voluntary Isometric Contraction |
| RF | Rectus femoris |
| RMS | Root mean square |
| RPE | Rating of Perceived Exertion |
| ST | Semitendinosus |
| VL | Vastus lateralis |
| VM | Vastus medialis |
| $VO_2$ | Oxygen consumption |
| 10-CS | 10-point cognitive screener |

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**BACKGROUND:** Evaluating exercise intensity is crucial for designing effective training programs and monitoring progress. The Rating of Perceived Exertion (RPE) scale, a subjective measure of effort, is commonly used for estimating exercise intensity. However, its applicability in specific conditions and populations, particularly in co-contraction training and older individuals, warrants further investigation.
**AIM:** Our main aim was to analyze the correlation between RPE and electromyographic (EMG) activity in co-contraction and conventional resistance training. We also compared muscle activity and RPE across training methods.
**METHOD:** Twenty-three older adults were allocated and divided into conventional resistance training (CRT) and co-contraction training (CCT). EMG activity and RPE were recorded for knee extension and flexion movement and knee co-contraction during training sets and correlated before and after eight weeks of training.
**RESULTS:** The results indicated no significant correlation between EMG activity and RPE for either training method. Additionally, EMG analysis showed higher EMG activity in the CRT than in the CCT. On the other hand, CCT demonstrated an increase in EMG activity after eight weeks of training.
**CONCLUSION:** In conclusion, RPE did not correlate with EMG activity, highlighting the need for finding accessible tools to assess exercise intensity, particularly in older people, and alternative training methods, such as co-contraction training.

**KEYWORDS**: No-load resistance training | Electromyography | Strength | Aging | Borg scale

## INTRODUCTION

Accurately assessing exercise intensity is essential for effective training programs [1], ensuring safety and monitoring progress [2]. Quantifying exercise intensity is usually based on mechanical, physiological, and psychological aspects, which can be subdivided into external and internal loads [3]. External load refers to the parameters that can be recorded during training (heart rate, HR), electromyographic (EMG) activity, oxygen consumption (VO2), and objective aspects of training (load, volume, sets, repetitions, duration, intervals, and rests of training) [3,4]. The internal load can be defined as an individual's physiological and psychological response during exercise and represents the subjective response to an external load (rating of perceived exertion, (RPE)) [3,4]. Furthermore, it is worth highlighting the importance of monitoring internal and external loads, especially for older adults, as the aging process can affect their ability to generate strength and withstand great efforts, as well as their executive and cognitive function [5]. Therefore, trainers and clinicians use different tools to monitor the internal and external loads of training [6,7]. However, among the plenty monitoring methods, RPE is a widespread and well-known resource, accepted for its convenience, easy application, and low cost [8–10] to measure internal load. RPE, commonly measured using the Borg scale, gauges effort and discomfort during exercise [8]. Research consistently validates its accuracy in estimating physiological effort, especially in aerobic exercise [9,11].

Recent evidence supports the validity of the Borg RPE scale in accessing internal load during resistance exercises [12]. However, in an exercise environment with multiple influencing factors (e.g., exercise type, practitioner's level of experience, practitioner's understanding of RPE), RPE's validity can be compromised, challenging its use for intensity monitoring [9]. Hence, additional studies are necessary to validate the RPE [1] for specific strength training methods [12], diverse populations (e.g., older adults, non-athletes), and exercises (e.g., more complex, isolated) [9,13,14]. Although RPE may be an alternative approach to monitoring internal load during strength training due to its easy implementation, fast application, and avoidance of maximal efforts, it is essential to state that these recommendations are based on a few studies with older adults [1]. Furthermore, some studies [10,14] show that RPE assessment has been used to assess effort throughout an exercise session and is a valid and reliable indicator for monitoring the overall intensity of resistance training sessions. This involves providing a global rating of the effort level for the entire training session rather than reporting acute RPE measurements for each exercise within a session. It appears reasonable to assume that performing a single exercise, particularly if it involves single-joint movements, might engage fewer muscle groups and potentially elicit a lower level of effort, which may not be accurately perceived by the participant and precisely measured using the Borg RPE scale. Nevertheless, further investigation is required to substantiate this assumption.

A novel resistance training method, voluntary co-contraction, has been developed and presented sufficient muscle recruitment to effectively enhance strength [15-17] and muscular hypertrophy [17,18]. This method involves simultaneous voluntary contractions of antagonist pairs of muscles (e.g., simultaneous contraction of elbow flexors and extensors muscles) without external devices [18]. Since voluntary co-contraction demands an organization of excitatory motor commands so that the muscles themselves produce resistive forces that act against each other [19], it is possible that it may pose challenges related to factors such as age, level of experience, and training [20]. Moreover, currently, there is no available tool to verify the intensity of co-contraction training other than assessing muscle activation during the training; unlike conventional resistance training, which can be accessed using methods such as RPE [12] and percentage of one-repetition maximum [21]. To date, no RPE scale has been specifically designed and validated for co-contraction training. To verify if RPE effectively measures resistance training intensity, it is crucial to investigate its correlation with physiological and performance parameters [13], such as heart rate, total weight lifted, and EMG activity. Some methods of monitoring resistance exercise intensities through external load require expensive equipment such as dynamometers and surface EMG recording [12]. EMG is widely applied in medical, neuroscience, and sports science areas [22] to assess muscle activity based on the electric potential detected from muscle fibers' transmembrane current (muscle excitation) [23]. This allows us to measure the intensity of the exercise based on the values of muscle activity, although with high equipment cost, time-consuming protocols [12], and technical knowledge [24]. Investigating the correlation between EMG and RPE could provide a more accessible and cost-effective way to assess intensity, benefiting practitioners and the public in practical settings.

The EMG activity recorded during contraction is related to the muscle-generated force, which influences the intensity of physical effort during the task. Therefore, it is reasonable to presume that the intensity of effort affects the perceived exertion. Furthermore, when interested in measuring localized muscle group effort, it is common to use EMG signals to investigate the level of muscular excitation during physical activities [25]. Additionally, different types of strength training can influence both intensity and perception of effort, considering factors such as exercise selection, rest periods and movement velocity [14]. How muscles are recruited can influence both EMG and RPE responses, given that co-contraction involves simultaneous recruitment of agonist and antagonist muscles, while conventional training often focuses on agonist recruitment. Finally, variations in muscle overload due to different types of exercises can also influence the responses of both EMG and RPE. Therefore, considering the potential influence of different kinds of exercises on muscle activity and perception of effort, it becomes interesting to analyze how these variables behave in response to different types of training. Furthermore, investigating the existence of a relationship between muscle activity measured by EMG and the RPE reported by participants can provide valuable insights into how these aspects interrelate in different training methods.

Thus, we analyzed the correlation between EMG activity (external load) and RPE (internal load) in co-contraction and conventional resistance training. Examining the relationship between RPE and EMG allows one to comprehend the most suitable approach for quantifying exercise intensity in resistance training, particularly co-contraction training. Considering the characteristics of the training session of our study (exercise programs only for knee muscles composed of few exercises) and the characteristics of our study population (older adults without previous experience of strength training), we assume that a correlation may not be observed. Additionally, we compared EMG activity and RPE across training types. Furthermore, isometric exercise substantially elevates blood pressure and heart rate [26]. Given limited knowledge of cardiovascular responses to co-contraction training in older individuals, we prioritized monitoring blood pressure and heart rate for safety.

## METHODS

### Trial design

This is a double-arm study of an eight-week supervised exercise program of conventional resistance training (CRT) or co-contraction training (CCT) for older adults (Figure 1). Participants completed an individual in-person assessment at baseline and at the end of the eight-week program to collect physical outcome measures. We acquired the EMG activity data of the lower limb muscles along with the corresponding RPE measurements. The study was approved by the local Research Ethics Board (#3.600.049) and complied with the Helsinki Declaration.

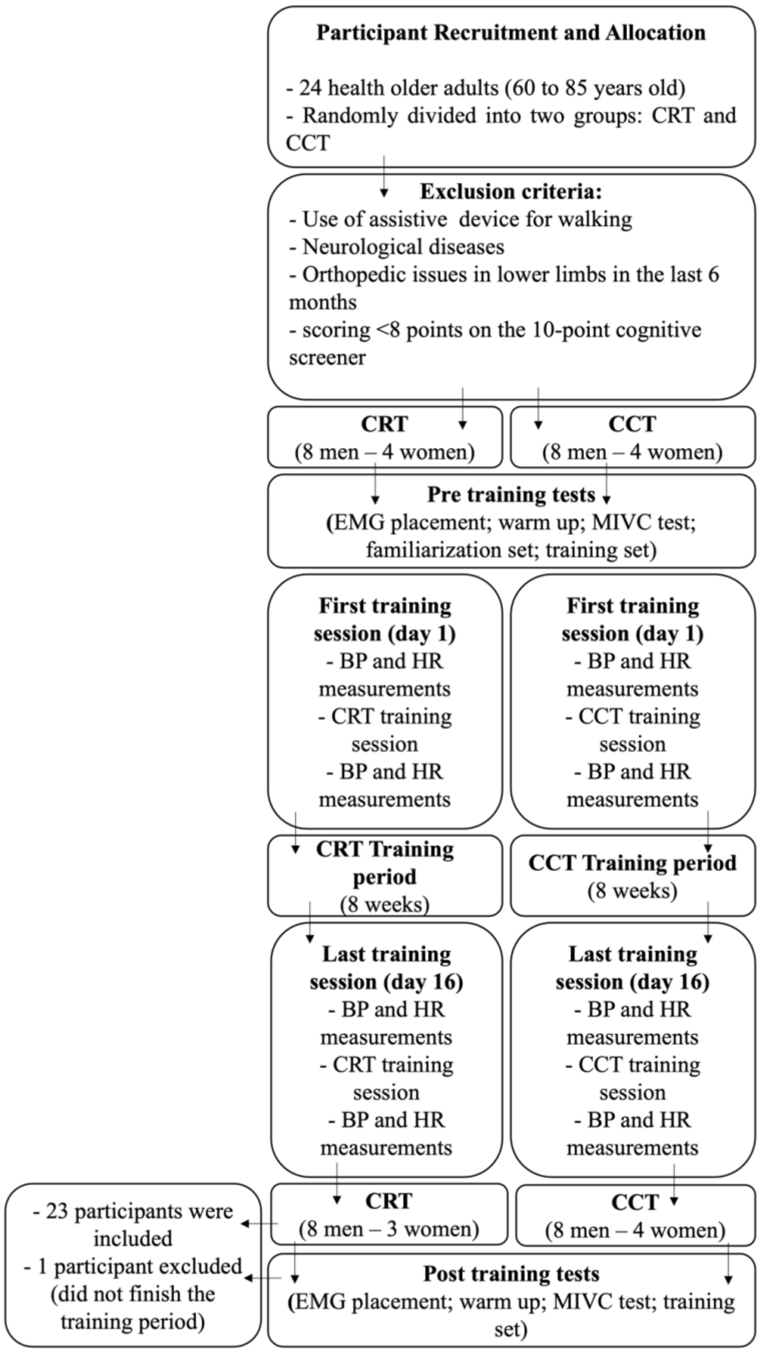


**Figure 1.** Study flowchart. CRT: conventional resistance training group; CCT: co-contraction training group; EMG: electromyographic activity; MVIC: maximal isometric voluntary contraction; BP: blood pressure; HR: heart rate.

### Participants

We determined the total sample size (n=12) using G*Power 3.1.9.4 software [27], employing a priori F test (ANOVA, repeated measures within-between interaction), with effect size (0.50) from a previous study [28] $\alpha$=0.05, and power=0.80.

Participants aged 60-85 years old were eligible if they were healthy older adults without experience in specific resistance training. Exclusions applied to those using walking aids, experiencing neurological diseases or orthopedic issues in lower limbs within the last six months, or scoring <8 points on the 10-point cognitive screener (10-CS) for cognitive impairment screening [29]. We also asked participants about their level of physical activity, using simple questions, just for characterization for the sample (if they practiced any physical activity, which ones, and what duration and frequency of practice). Upon enrollment, participants were randomly assigned to one of the groups (CCT or CRT) by drawing until the sample size of each group was completed.

### Procedures

Both exercise programs were conducted for eight weeks. Exercise sessions were delivered twice-weekly by a registered kinesiologist. We focused on the baseline and post-intervention sessions to explore the potential correlation between EMG activity and RPE. For detailed information regarding the exercises in the CRT and CCT programs, see the Supplementary Material.

At baseline and post-training periods, we placed five wireless EMG surface sensors (composed of four 16-bit channels - four silver contact bars (10x1 mm) with a distance of 10 mm between them - Trigno Wireless; Delsys®, Natick, Massachusetts, USA) over the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), semitendinosus (ST), and biceps femoris long head (BF) following SENIAM recommendations [30]. For baseline EMG data collection, we created maps of the participants' thighs using transparent plastic material. This allowed us to mark the placement of the electrodes with greater precision by considering skin marks for guidance, such as moles, scars, tattoos, and visible veins. This approach ensures greater accuracy in repositioning the electrodes after training. We collected participants' EMG activity of knee extensors and flexors muscles during Maximal Voluntary Isometric Contraction (MVIC) tests and a training set. EMG signals were sampled at 2,000 Hz. In the CCT group, we employed an isokinetic dynamometer (Biodex, System 4 Pro, New York, NY, USA) to collect the MVIC to normalize the EMG signal. In the CRT group, we used an extension machine (Flex Fitness Equipment, Cedral, São Paulo, Brazil) to record the MVIC and subsequent EMG normalization. The MVIC peak normalized the EMG values.

For the CCT group, after placing the EMG sensors, participants performed a warm-up on the isokinetic dynamometer that consisted of five submaximal isometric knee extensions and five submaximal isometric knee flexions (5 seconds of effort between 90-second intervals). They sat with their hips flexed at 90° and knees flexed at 60°. The knee joint was aligned with the axis of the dynamometer. Following the warm-up, the participants performed three five-second MVICs with 90-second intervals between them. The CRT group, after placing the EMG sensors, performed the MVICs for knee extension and knee flexion using the knee extension machine (Flex Fitness Equipment, Cedral, São Paulo, Brazil). The participants were positioned at the machine following the previously mentioned positioning: 90° of hip flexion and 60° of knee flexion. We used a goniometer to verify these angles.

Following the MVIC tests, participants rested for 90 seconds, and the CCT group performed the familiarization with five to seven submaximal co-contractions. For the CRT group, after 90 seconds of rest, they performed 10 maximal repetitions in the leg extension exercise machine and leg curl exercise to estimate the 1 repetition maximal (1RM) load from Brzycki's [31] equation. After the RM test, they rested for 90 seconds and performed five to seven repetitions of each exercise using a 40% 1RM load for familiarization.

For the training set, the CRT group performed a set of 10 repetitions for knee extension (from 90° degrees of flexion to full extension - 180°), at leg extension (Flex Fitness Equipment, Cedral, São Paulo, Brazil) and 10 repetitions of knee flexion (from 0° degrees - full extension - to 90° of flexion), at prone leg curl (Flex Fitness Equipment, Cedral, São Paulo, Brazil) without rest between exercises. For both exercises, the intensity was set at 70% 1RM. The CCT group performed a set of 10 isometric co-contractions, with the knee at 60° of flexion (assessed with a goniometer), in a common chair (with back and without armrests), composed of four seconds of effort followed by four seconds of rest. Immediately after the end of each exercise set (i.e., baseline and post-intervention sessions), CRT and CCT groups indicated their RPE based on the CR-10 Borg scale [32]. The scale was presented as a printed table together with written explanations. The scale ranges from 0 to 10, where 0 represents "no exertion" (at rest) and 10 indicates the maximum possible exertion. The scale was verbally explained to the participants before the experiment onset. To choose the value that best represented their exertion, participants were instructed to look at the written expressions on the CR-10 Borg scale and then select a number corresponding to the written expression.

We measured the systolic and diastolic blood pressure and heart rate at the beginning and end of all training sessions using a blood pressure monitor (model HEM-6124, Omron Healthcare Co., Kyoto, Japan). In the present study, we presented only the data from the first and last (sixteenth) training sessions.

### Data Analysis

The raw EMG signals were band-pass filtered (Butterworth, fourth-order, 10–500 Hz), full-wave rectified, and processed to compute the root mean square (RMS). The first and last contractions were omitted from our analysis to maintain consistency and accuracy. Consequently, we examined eight contractions per exercise for the CRT group and eight co-contractions for the CCT group. For normalization, the RMS values of each muscle vector were scaled to a MVIC recorded for each muscle at the start of every testing session. Finally, the RMS values regarding each contraction were averaged. All these procedures were performed using a script written in Python (Python Software Foundation, Wilmington, DE, USA).

### Statistical Analysis

The normality and homogeneity of variances were assessed using the Shapiro-Wilk and Levene's tests, respectively. When the assumptions of normality and homoscedasticity were not met, we transformed the data using the square root and 1/square root methods. Independent-sample t-tests were employed for the anthropometric variables. We calculated a bivariate Pearson's correlation to verify the relationships between RPE and muscle activity (Pre- and Post-intervention). We used separate two-way repeated measures analysis of variance (ANOVA) [Group (CRT vs. CCT) X moment (Pre vs. Post)] to identify changes in RPE and muscle activity. We also used two-way ANOVAs to identify changes in heart rate, systolic blood pressure, and diastolic blood pressure during the training in the first and sixteenth training sessions [Group (CRT vs. CCT) X moment (Initial vs. Final)]. When significant interaction effects were identified in the ANOVA, we used Bonferroni's post-hoc tests. The standardized magnitude of any significant changes was determined by calculating effect sizes (Hedges' g) [33]. We considered effect sizes as small (d = 0.2), medium (d = 0.5), and large (d = 0.8). The level of significance was set at $p<0.05$ for all analyses. All statistical analyses were performed with IBM SPSS Statistics for Macintosh (IBM Corp. Version 29.0. Armonk, NY, USA).

## RESULTS

### Demographic

Twenty-three active (i.e., ≥150 min/week of physical activity – activities were walking, exercising in public spaces and squares without supervision, water aerobics, and group exercises with supervision - circuit style) older adults participated in this study: CRT group: 8 men and 3 women; age 68.4±6.2 years old; body mass 74±18.1kg; height 1.61±0.12m; and CCT group: 8 men and 4 women; age 69.2±4.1 years old; body mass 67±12.6kg; height 1.61±0.07m. There were no differences between groups for sample characterization, age ($t(10) = -0.385$, $p = .583$, Hedges' g = -0.107, CI: -0.652, 0.443), body mass ($t(10) = 1.248$, $p = .346$, Hedges' g = 0.347, CI: -0.226, 0.905), and height ($t(10) = 0.385$, $p = .901$, Hedges' g = 0.046, CI: -0.501, 0.590).

### Correlations between EMG and RPE

We found no significant correlations between EMG data and RPE, either individually or when we combined all muscles for CRT (Figure 2) and CCT (Figure 3) groups, whether pre- or post-training.

### EMG

Figure 4 presents the EMG values for both groups in the pre- and post-training periods.

*Rectus Femoris muscle*

The ANOVA revealed main effect of group ($F(1,19) = 27.239$, $p < .001$, $\eta p2 = 0.589$) and interaction between moment and group ($F(1,19) = 6.231$, $p = .022$, $\eta p2 = 0.247$). Post-hoc tests pointed differences between groups in pre- (Hedges' g = 2.843, CI: 1.664, 3.989) and post-training periods (Hedges'g = 1.381, CI: 0.436, 2.297). In both moments, the CRT group showed higher EMG activity for the rectus femoris than the CCT group. Also, EMG activity was higher for the CCT group post- than pre-training (Hedges'g = 0.841, CI: -1.509, -0.142). There was no effect of the moment ($F(1,19) = 2.143$, $p = .160$, $\eta p2 = 0.101$).

*Biceps Femoris muscle*

There was a main effect of group ($F(1,20) = 50.234$, $p < .001$, $\eta p2 = 0.715$) and interaction between moment and group ($F(1,20) = 9.865$, $p = .005$, $\eta p2 = 0.330$). Post-hoc revealed differences between groups pre- (Hedges' g = 2.792, CI: 1.625, 3.927) and post-training periods (Hedges'g = 2.330, CI: 1.234, 3.394). The CRT group showed higher EMG activity for the biceps femoris than the CCT group. Moreover, EMG activity for the CCT group was higher after the training period than before (Hedges'g = 0.921, CI: -1.556, -0.258). There was no main effect of moment ($F(1,20) = 0.041$, $p = .841$, $\eta p2 = 0.002$).

*Vastus Lateralis muscle*

The ANOVA exhibited only a main effect for group ($F(1,17) = 65.192$, $p < .001$, $\eta p2 = 0.793$). Regardless of moment, the CRT group showed higher EMG activity than the CCT group. There was no effect for moment ($F(1,17) = 1.406$, $p = .252$, $\eta p2 = 0.076$) and no interaction between moment and group ($F(1,17) = 2.182$, $p = .158$, $\eta p2 = 0.114$).

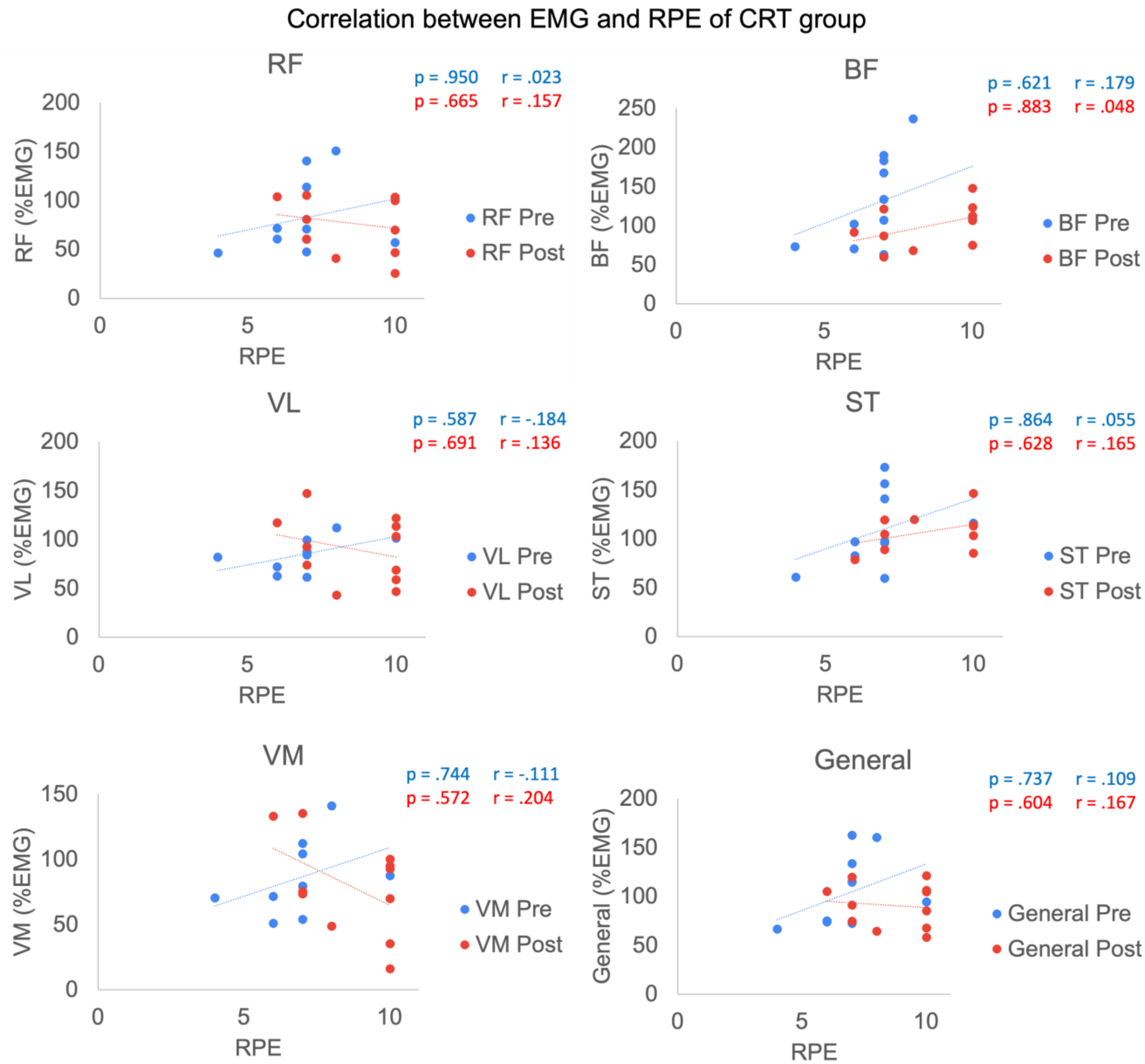


**Figure 2.** Scatterplot between electromyographic activity (EMG) and Rated Perceived Effort (RPE) for pre- (red) and post-intervention (blue) for the conventional resistance training (CRT) group. Pearson correlation (r) values are presented in red (pre-training) and blue (post-training). RF: rectus femoris; VL: vastus lateralis; VM: vastus medialis; BF: biceps femoris long head; ST: semitendinosus; General: all muscles together; Pre: set pre-training period; Post: set post-training period.

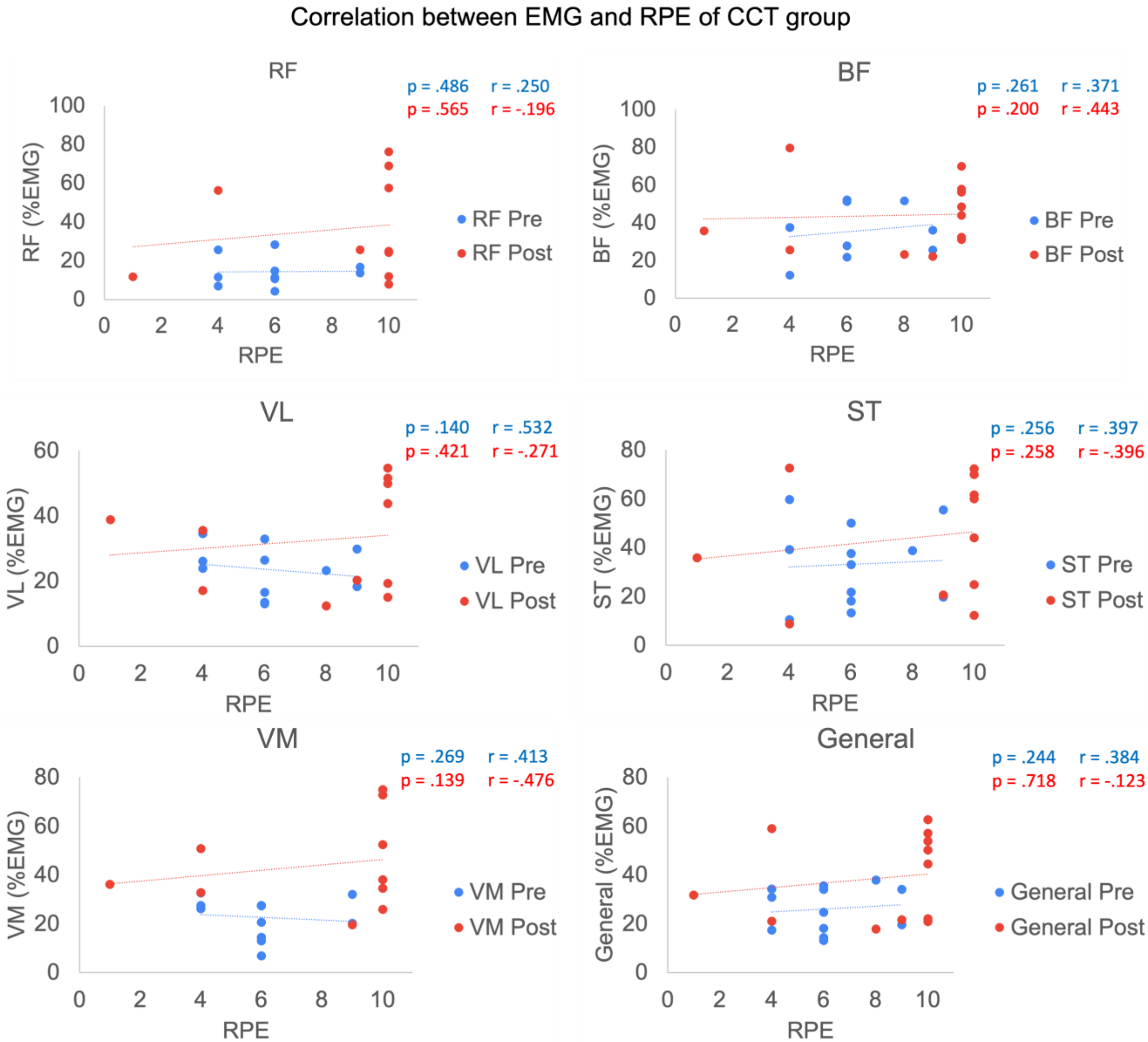


**Figure 3.** Scatterplot between electromyographic activity (EMG) and Rated Perceived Effort (RPE) for pre- (red) and post-intervention (blue) for the co-contraction training (CCT) groups. Pearson correlation (r) values are presented in red (pre-training) and blue (post-training). RF: rectus femoris; VL: vastus lateralis; VM: vastus medialis; BF: biceps femoris long head; ST: semitendinosus; General: all muscles together; Pre: set pre-training period; Post: set post-training period.

*Semitendinosus muscle*

The ANOVA identified a main effect for group ($F(1,19) = 49.958$, $p < .001$, ηp2 = 0.724). The CRT group showed higher EMG activity regardless of moment than the CCT group. There was no main effect for moment ($F(1,19) = 0.498$, $p = .489$, ηp2 = 0.026) and no interaction between moment and group ($F(1,19) = 0.664$, $p = .425$, ηp2 = 0.034).

*Vastus Medialis muscle*

There was a main effect for group ($F(1,16) = 22.159$, $p < .001$, ηp2 = 0.581) and an interaction between moment and group ($F(1,16) = 9.523$, $p = .007$, ηp2 = 0.373). Post hoc indicated that groups only differed in pre-training (Hedges'g = 2.300, CI: -3.408, -1.156). The CRT group showed higher EMG activity than the CCT group. Also, the CCT group showed higher EMG activity in the post- than in the pre-training periods (Hedges'g = 0.853, CI: 0.117, 1.554). There was no main effect for moment ($F(1,16) = 0.760$, $p = .396$, ηp2 = 0.045).

*General EMG (all muscles together)*

Regarding general EMG activity, the ANOVA showed a main effect for group F(1,21) = 58.151, $p < .001$, ηp2 = 0.735), and an interaction between moment and group (F(1,21) = 8.279, $p = .009$, ηp2 = 0.283). Post-hoc revealed that the CRT group showed higher EMG activity than CCT during the pre- (Hedges'g = 2.920, CI: 1.725, 4.084) and post-training periods (Hedges'g = 2.515, CI: 1.407, 3.591). There was no main effect for moment (F(1,21) = 0.006, $p = .941$, ηp2 = 0.000).

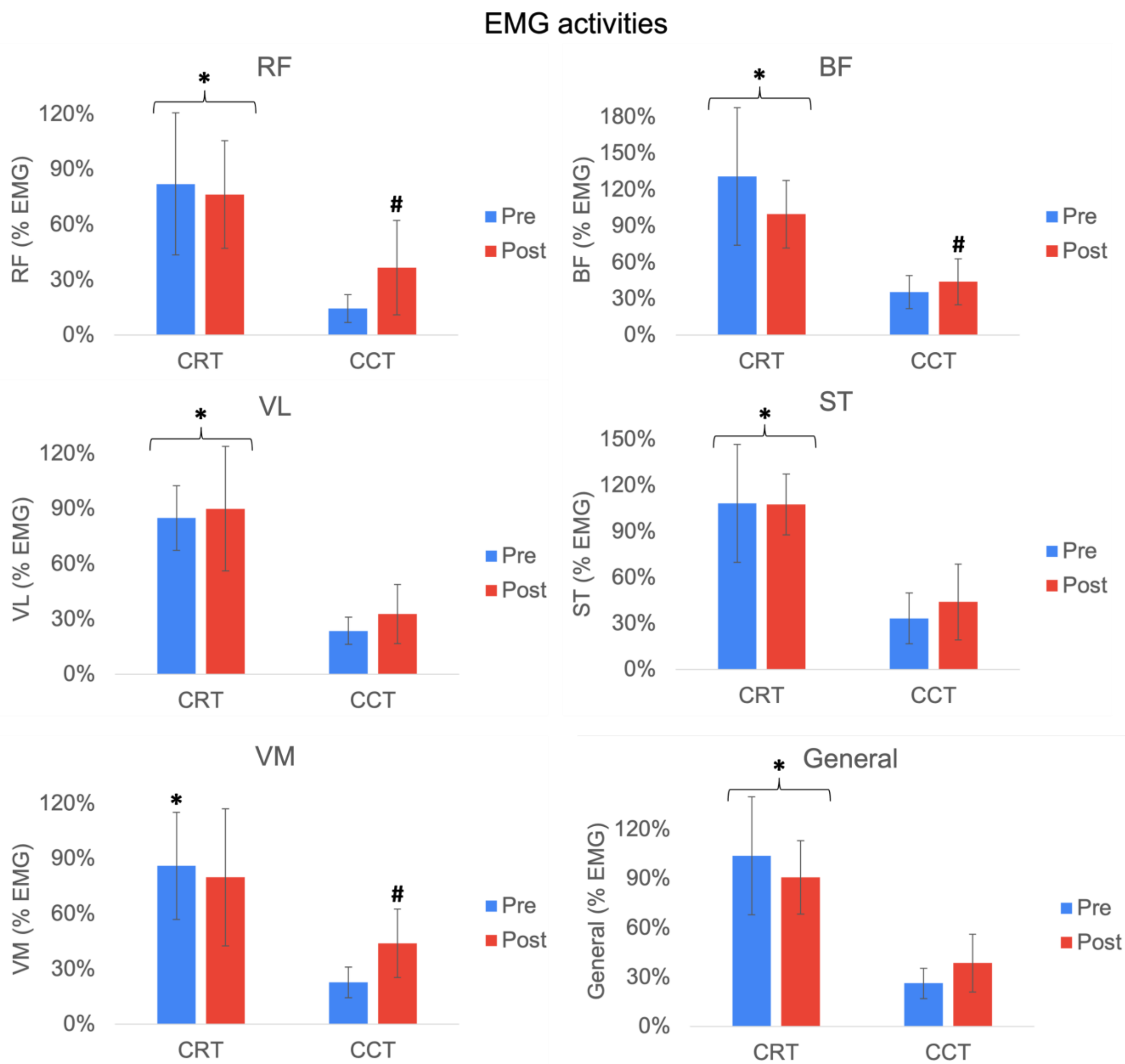


**Figure 4.** Mean and standard deviation of electromyographic activity (EMG %) of analyzed muscles. RF: rectus femoris; VM: vastus medialis; VL: vastus lateralis; BF: biceps femoris long head; ST: semitendinosus; General: all muscles together; Pre: set pre-training period; Post: set post-training period; CRT: conventional resistance training group; CCT: co-contraction training group; * different compared to CCT; # different between moments.

## RPE

The ANOVA showed an effect for moment (F(1,21) = 15.941, $p < .001$, ηp2 = 0.432), indicating that RPE was larger after the training period, regardless of group (Table 1). No effect for group (F(1,21) = 0.800, $p = .381$, ηp2 = 0.037), and no interaction between moment and group (F(1,21) = 0.014, $p = .906$, ηp2 = 0.001) was found.

### Physiological variables

Table 1 presents the physiological values for both groups in the first and last training sessions.

**Table 1.** Values of mean and standard deviation (±) of Rate of Perceived Exertion (RPE), Heart Rate (HR), and Blood Pressure in the first (1st) and last (16th) training sessions.

Mean and Standard Deviation of RPE in Training Set

| CRT group | | CCT group | |
|---|---|---|---|
| Pre | Post | Pre | Post |
| 6.9 ±1.4 | 8.6 ±1.6 **#** | 6.2 ±1.7 | 8.0 ±3.2 **#** |

Mean and Standard Deviation of HR and Blood Pressure

| CRT group | | CCT group | | CRT group | | CCT group | |
|---|---|---|---|---|---|---|---|
| First Session | | | | Last Session | | | |
| Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| HR (bpm) | | | | | | | |
| 75.4 ±13.6 | 84.3 ±13.7 | 74.7 ±11.6 | 76.7 ±11.6 * | 75.4 ±14.7 | 91.6 ±17.9 | 74.2 ±10.6 | 76.3 ±9. 6 * |
| SBP (mmHg) | | | | | | | |
| 131.8 ±20.9 | 144.5 ±21.1 **#** | 134.2 ±24.7 | 138.3 ±24.4 **#** | 136.4 ±15.7 | 147.3 ±21.5 **#** | 130.8 ±19.7 | 138.3 ±16.4 **#** |
| DBP (mmHg) | | | | | | | |
| 82.7 ±15.5 | 83.6 ±11.2 | 81.7 ±13.4 | 82.5 ±12.1 | 89.1 ±18.7 | 89.1 ±10.4 | 81.7 ±10.3 | 80.8 ±10.0 |

Pre: pre-session; Post: post-session; CRT: conventional resistance training group; CCT: co-contraction training group; * statistical difference between groups; # statistical difference between moments.

*First training session*

Heart Rate

There was an effect for moment ($F(1,21) = 18.227$, $p < .001$, $\eta p2 = 0.465$) and a significant interaction between groups and moment ($F(1,21) = 7.311$, $p = .013$, $\eta p2 = 0.258$). The CRT group showed higher heart rate values at the end of the first training session (Hedges' g = 0.047, CI: -0.742, 0.835). There was no effect for group ($F(1,21) = 0.632$, $p = .435$, $\eta p2 = 0.029$).

Systolic blood pressure

The ANOVA showed an effect for moment ($F(1,21) = 11.061$, $p = .003$, $\eta p2 = 0.345$). Systolic blood pressure was higher at the end of the training session than at the beginning, regardless of the group. No effect for group ($F(1,21) = 0.044$, $p = .836$, $\eta p2 = 0.002$) and no interaction between groups and moment ($F(1,21) = 2.840$, $p = .107$, $\eta p2 = 0.119$) was found.

Diastolic blood pressure

There was no effect for moment ($F(1,21) = 0.309$, $p = .584$, $\eta p2 = 0.015$), group ($F(1,21) = 0.044$, $p = .837$, $\eta p2 = 0.002$) or interaction between group and moment ($F(1,21) = 0.001$, $p = .981$, $\eta p2 = 0.000$).

*Last training session (sixteenth)*

Similar patterns were observed for all physiological data as in the first training session.

Heart Rate

There was an effect for the moment ($F(1,21) = 50.100$, $p < .001$, $\eta p2 = 0.705$), and a significant interaction between groups and moment ($F(1,21) = 29.849$, $p < .001$, $\eta p2 = 0.587$). The CRT group showed higher heart rate values at the end of the last training session (Hedges' g = 1.043, CI: 0.184, 1.881). There was no effect for group ($F(1,21) = 2.284$, $p = .146$, $\eta p2 = 0.098$).

Systolic blood pressure

The ANOVA showed a significant main effect for the moment ($F(1,21) = 5.906$, $p = .024$, $\eta p2 = 0.219$). Systolic blood pressure was higher at the end of the last training session than at the beginning, regardless of the group. No significant effect for group ($F(1,21) = 1.160$, $p = .294$, $\eta p2 = 0.052$) and for interaction between groups and moment ($F(1,21) = 0.203$, $p = .657$, $\eta p2 = 0.010$) was found.

Diastolic blood pressure

There was no effect for moment ($F(1,21) = 0.025$, $p = .875$, $\eta p2 = 0.001$), group ($F(1,21) = 1.160$, $p = .106$, $\eta p2 = 0.120$) and interaction between group and moment ($F(1,21) = 0.025$, $p = .875$, $\eta p2 = 0.001$).

## DISCUSSION

Our study assessed the correlation between EMG and RPE in co-contraction and conventional resistance training. Our main finding was the absence of a significant correlation between EMG activity and RPE for either training modality. Additionally, the CRT group consistently exhibited higher EMG activation than the CCT group for muscles analyzed. However, only the CCT group increased muscle activity after the 8-week training program.

While different studies have shown the benefits of co-contraction training with promising results for gains in strength [15–18] and hypertrophy [17,18], most have primarily relied on EMG activity for assessing external load [20,34]. Moreover, only two studies used RPE to assess internal load during co-contraction [34,35]. Furthermore, no study sought to correlate the RPE with EMG activity to check whether the RPE would be a possible measure of training intensity for the co-contraction modality. Notably, these investigations predominantly focused on the upper limb (elbow extensors and flexors) and enrolled younger participants. We identified only two studies [36,37] that used co-contraction training for lower limbs (knee and ankle extensors and flexors) and older people, with only one [36] using EMG activity to verify muscle activation.

Despite the lack of correlation between RPE and EMG in our results for conventional resistance training, RPE has been used as a valid measure of intensity during resistance exercise. A recent systematic review with meta-analysis [7], which included 70 studies regarding RPE and resistance training in healthy participants, showed that the RPE validly measures exercise intensity and physiological effort during resistance training. However, different experimental designs have produced conflicting results when using RPE in a resistance exercise setting [7]. In this sense, our results may also have been influenced by certain factors, including the impact of aging on the perception of effort [8,13,14,24], level of experience [7], and type of exercise/modality [11,24]. This effect can be observed even in submaximal exercises, as seen in our experiment.

Older people can misjudge their perception of exertion when using the RPE [7]. It is known that natural aging results in a decrease in muscle strength and physical capacity, largely mediated by changes in the neuromuscular system. As a result, evidence suggests that the ability to perceive the intensity of a muscle contraction accurately may be altered in older adults, which is reflected in the RPE based on the CR-10 scale [38]. Older adults exhibit non-linear perceived exertion responses and knee extensor torque, corresponding to an overall perceptual underestimation [38]. Somatosensory changes in aging may alter the perception of physical effort during voluntary muscle contractions, as this is the result of multiple sensory inputs originating from mechanoreceptors and musculotendinous, articular, and cutaneous sources linked to higher cognitive processes. Age-related changes in these aspects may interfere with the perceptual acuity of voluntary muscle contractions. Finally, it was shown that younger individuals may produce higher RPE scores than older individuals for the same intensities during estimation tasks [7], suggesting that RPE can be altered in older individuals.

Similarly, experience in the training modality can also influence RPE [11,24]. It has been demonstrated that novices are less accurate in representing the actual training load, assigning lower RPE scores than well-trained participants. This occurs even with relatively low training volumes [7]. This may be related to our results, as our older participants had no specific strength training experience and had a low training volume (twice-weekly, with one or two lower limb exercises, depending on the training group). Also, the type of exercise may influence the perception of effort. We speculate that differences in muscle activation patterns can affect both EMG and RPE responses. This is because co-contraction simultaneously activates agonist and antagonist muscles, whereas conventional training typically emphasizes agonist recruitment. Moreover, evidence shows that RPE works as a global/general measure of intensity [10,14] for an entire training session, not just for a series, or even for the sensation of the whole body and not just one limb or muscle group. Furthermore, it is suggested that perceived exertion is related to the combined effect of several active muscles and not just the activity of individual muscles [25].

However, only a few studies have examined the perceived exertion response to isolated muscle contractions in older adults and have demonstrated divergent results [7,38]. The discrepancies in validity coefficients and contradictory findings related to the topic [7] confirm the need for RPE validity during resistance exercise and a deeper understanding of which factors affect it during different resistance exercises and modalities. More studies are also needed to test the effectiveness of RPE in specific conditions and individuals, such as older adults.

Our results showed higher muscle activation in conventional resistance training than co-contraction training. This difference can be attributed to the external load since participants lifted a pre-established external load in traditional training. In contrast, in CCT, effort relied on learning to co-contract muscles for resistance. Participants faced challenges in performing the co-contraction task, leading to a lower percentage of muscle activity in the CCT group. More studies have investigated the level of muscle activity during maximal voluntary co-contraction in the thigh muscles [36]. However, regarding upper limbs [16,39], it has been suggested that some factors may limit the maximum activation of antagonist muscles during co-contraction, including influences of inhibitory systems at central and peripheral levels, as well as dual-task interference and reciprocal inhibition, causing the muscles involved not being fully activated. Furthermore, aging may affect the ability to perform maximal voluntary co-contraction. With aging, there is a natural tendency to lose muscle mass and changes in the properties of muscle fibers, which can lead to a decrease in the muscles' ability to generate force [40] during co-contraction. Changes in the central nervous system resulting from aging can also decrease the efficiency of neural signals that control muscle contraction [40], resulting in a less coordinated muscular response.

However, we found an increased muscle activation in Vastus Lateralis, Rectus Femoris, and Biceps Femoris muscles post-training in the CCT group, which may indicate improved co-contraction proficiency [41]. This could also explain the increase in RPE values for the CCT group after the training period. This improvement in muscle activation is probably due to the eight-week co-contraction training program. Despite age-related changes in the motor control system, the potential to learn motor skills is preserved in older adults with extended practice [42]. For the conventional training group, RPE increase may be linked to load adjustments made throughout the eight weeks of training. Heart rate and blood pressure data during training revealed that co-contraction is as safe as conventional training methods. As expected from resistance training, both training increased systolic blood pressure [43], but not diastolic blood pressure. A higher heart rate in the CRT group was expected since they performed greater effort (higher percentage of EMG activity) than the CCT. Our study is the first to demonstrate physiological indicators related to cardiovascular safety during co-contraction training performed by older adults.

As a limitation of this study, while co-contraction involves an isometric pattern of movement and training intensity cannot be controlled, the conventional resistance training method employs a dynamic movement pattern, and we could adjust the load to 70% 1RM. Given this, some characteristics of the protocols, such as exercise load, volume, execution speed, range of motion and load progression, could not be fully equalized. Despite our efforts to standardize the time under tension for each method, the differences between training methods may have influenced the adaptive responses to training and, consequently, impacted the relationships between EMG and RPE measures. Furthermore, another important point to highlight among the study limitations is that the collection of MVIC was performed using different equipment for the CCT group (isokinetic dynamometer) and the CRT group (knee extension machine). Despite this, we maintained the hip and knee angles during data collection to be equal for both groups and the muscle activation patterns for maximum EMG to be similar. Lastly, this study relied on a dataset based on only one set of exercises from the two modalities (1 set of 10 co-contractions and 1 set of 10 repetitions of knee flexion and extension). A more comprehensive analysis, such as the entire training series (5 sets of 10 co-contractions and 4 sets of 8-12 repetitions of traditional training), as well as the whole duration of the training program (all sixteen sessions instead of only pre and post-training), could yield more robust results. However, this study was the first attempt to investigate co-contraction training intensity through the correlation of RPE-EMG activity.

Further research is needed to examine whether aging can interfere with RPE and to further explore potential physiological moderating factors that could lead to different RPE results among different populations and types of exercise, as well as to determine whether RPE reliably measures exercise intensity, especially in co-contraction training. These parameters would allow future studies and interventions to use appropriate RPE scales and adapt their protocols depending on the characteristics of the exercise and the participant. Otherwise, a validated scale for older adults and these training methods will be necessary to ensure their specific characteristics are considered. So far, the insights from this research suggest to professionals working with sports training, rehabilitation practices, and exercise prescription in clinical settings that RPE is not a reliable measure to evaluate the intensity of co-contraction and traditional training for thigh muscles in older adults. Therefore, alternative methods and indicators of intensity assessment need to be considered during the analyzed exercises.

## CONCLUSION

The RPE did not correlate with EMG activity during a single set of conventional and co-contraction resistance training performed by older people. While EMG is a valuable external load measurement tool for evaluating muscular recruitment, its high cost and requirements challenge daily usage. Our attempt to substitute the costly and complex EMG tool with the simple, cost-free internal load measurement RPE method was not met. More investigations are needed to confirm whether RPE is not an appropriate indicator for measuring internal load measurement in resistance training, especially when performing co-contraction training in the older population. Depending on this, it is possible to develop an accessible and user-friendly tool for assessing exercise intensity and different resistance training modalities in older adults.

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