

Effect of antagonist activation on agonist muscle activity during strength training

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Abstract:

Background. Strength training, essential for fitness and rehabilitation, relies on the coordinated action of agonist and antagonist muscles. The agonist muscle is responsible for the primary movement, while the antagonist muscle is crucial for stabilization, controlling movement speed, and injury prevention. Recent research has investigated the advantages of including antagonist muscle activation in training programs, which has led to the creation of MAA training methods. This study compares the median frequency (Fmed) values of the electromyography (EMG) signal in the agonist muscle during agonist/antagonist (MAA) and traditional (MT) strength training protocols in experienced male athletes. **Materials and methods.** This cross-sectional study involved 12 volunteers aged 18–35 years. On the first day, each volunteer's maximum load for 10 repetitions (10RM) was determined for the extensor chair, flexor table, biceps curl, and triceps curl exercises. On the second day, participants were divided into two groups. One group performed a series of MT first, followed by a series of MAA two hours later. The other group started with MAA and then performed the MT series after two hours. Finally, a comparison between the extensor chair and biceps curl exercises was performed using the Student's t-test for dependent samples. All procedures assumed $\alpha = 0.05$ for statistical significance. All data were processed in Matlab version 2020.b (The MathWorks, USA). **Results.** The Fmed values for the extensor chair test at a 10RM load (101.6 ± 20.2 kg) were 78.1 ± 4.3 Hz with MT and 79.1 ± 3.4 Hz with MAA, demonstrating no significant difference ($p = 0.856$). For the biceps curl test at a 10RM load (27.5 ± 5.1 kg), the Fmed values were 75.6 ± 0.96 Hz with MT and 77.0 ± 3.1 Hz with MAA, also showing no significant difference ($p = 0.640$). **Conclusion.** Assessment of Fmed revealed no significant differences between MAA and MT in upper and lower limb exercises among men with strength training experience.

Keywords: Strength training; Agonist; Antagonist; Electromyography; Physical Education

Introduction

Strength training consists of a variety of exercises and training techniques that can lead to both acute and chronic adaptations, including increased strength (Del Vecchio et al., 2019; Suchomel et al., 2018), muscle hypertrophy (Schoenfeld et al., 2017), enhanced muscle endurance (Mendes et al., 2020; Silva et al., 2019; Materko & Santos, 2015; Materko et al., 2010), improved maximal muscle power (Behm et al., 2015), and overall better health (Santos et al., 2020; Maestroni et al., 2020).

While various scientifically supported methods of strength training exist, it is evident that the traditional approach (MT) remains the most commonly used in gyms. This approach focuses on targeting a single muscle group through multiple sets (Paz et al., 2014). Additionally, the agonist/antagonist method (MAA), also known as the super-set method, involves performing two exercises in succession without rest, engaging two opposing muscle groups (Gomes et al., 2014; Nobre et al., 2012). This method has been shown to be more effective for achieving strength and hypertrophy gains (Nascimento et al., 2019; Peuckert & Feldmann, 2017; Paz et al., 2014; Nobre et al., 2012) and improving athletic performance (Anjum et al., 2016; Nelson et al., 1986) compared to the MT method.

Research indicates that conditioning activities involving antagonist exercises have been shown to enhance performance in agonist activities, suggesting a beneficial interplay between these muscle groups (Hortobágyi et al., 2022). In this context, the activation of antagonist muscles during strength training can significantly influence the performance of agonist muscles (Miranda et al., 2021).

Electromyography (EMG) is widely recognized as a gold-standard quantitative method for evaluating the progression of neuromuscular activity (Viddeleer et al., 2012). The median frequency (Fmed) of the EMG signal, which is defined as the frequency that divides the power spectrum into two equal power regions, is an effective indicator for identifying physiological muscle fatigue (Bandeira et al., 2009) and for classifying the predominant types of muscle fibers (Pizzato et al., 2007). Therefore, the use of EMG-derived Fmed provides a more accurate

and objective assessment of physiological responses to different training regimens than relying solely on strength or hypertrophy measurements.

This study is justified as a critical gap in the literature by directly comparing the effects of MT and MAA on neuromuscular fatigue, as measured by EMG Fmed in experienced male strength training practitioners. This approach provides a more nuanced understanding of the underlying physiological mechanisms driving the observed differences between training methods, and differs from previous studies that have primarily focused on strength and hypertrophy outcomes (Nascimento et al., 2019; Peuckert & Feldmann, 2017; Paz et al., 2014; Nobre et al., 2012). The results will provide valuable insights for strength training professionals seeking short-term, effective training protocols and contribute to the development of evidence-based training strategies.

Existing research comparing MT and MAA has primarily focused on strength and hypertrophy outcomes, neglecting a detailed analysis of neuromuscular fatigue using objective measures such as EMG Fmed. This study addresses this gap by investigating the differential effects of MT and MAA on neuromuscular fatigue in experienced male strength trainers, providing a more comprehensive understanding of the physiological mechanisms underlying the effectiveness of each method. This is in the context of the ongoing search for optimal strength training protocols, with a focus on short-term efficacy and objective physiological assessment, highlighting its originality and importance in the field of neuromuscular training.

This quantitative approach, using a gold standard neuromuscular assessment technique, provided a more accurate and objective comparison than previous studies that relied solely on strength or hypertrophy measurements. Consequently, the aim of this study was to analyze the behavior of the Fmed values of the EMG signal between MAA and MT methods in experienced male strength training practitioners.

Materials and methods

Subjects

This cross-sectional study was performed with a sample of 12 male volunteers aged 18–35 years, who were randomly selected at a bodybuilding gym in Macapá-AP. The inclusion criteria required participants to have at least six months of experience in strength training, to refrain from using ergogenic aids, and to have no history of musculoskeletal injuries, along with no signs or symptoms indicating cardiopulmonary or metabolic diseases. All sessions were scheduled between 1:00 PM and 4:00 PM, with an ambient temperature of approximately 22°C. All volunteers received prior instructions to avoid exercise in the 24 h leading up to the study, refrain from consuming caffeinated substances (Hallehandre & Materko, 2018; Materko and Santos, 2011), and maintain adequate hydration during the tests. Experimental procedures began only after obtaining verbal consent and having participants sign an informed consent form, which was approved (no. 1.886.643) by the Institutional Research Ethics Committee and performed in compliance with Resolution 466/2012 of the National Health Council.

Body Composition Assessment

Height was assessed using a portable stadiometer (Sanny, Brazil) with an accuracy of 0.2 cm. Relative body fat and body mass were estimated through bioimpedance analysis using the HBF514C model (Omron, Brazil), which operates at a single frequency of 50 KHz, generating a constant alternating current of 500 mA. This procedure adhered to the bioimpedance usage guidelines established by Lukaski and coworkers (1986).

Experimental Procedures

This study was performed over two days, one week apart. On the first day, participants underwent a familiarization test to become acquainted with the protocols and equipment used in the tests aimed at reducing difficulties during the strength test (Materko et al., 2007). After the familiarization tests, the maximum repetition test protocol began with a warm-up consisting of 15 repetitions at 40% of body weight.

After a three-minute rest period, the protocol was implemented to determine the subject's maximum load for 10 repetitions (10RM) for the specified exercises. This protocol included five attempts, with a three-minute interval between each attempt, during which load adjustments were made until the subject achieved their 10RM for all exercises. Additionally, a five-minute recovery interval was allowed between exercises to perform the 10RM test because it engaged multiple muscle groups.

On the second day of data collection, seven days after the initial test, subjects were instructed on the exercise sequences. For the MT, the sequence included (1) an extension chair (Life Fitness, Brazil) and (2) a biceps curl on a low pulley (Star Trac, USA). For the MAA, the sequence comprised: (1) flexor table (Matrix, Brazil), (2) extension chair (Life Fitness, Brazil), (3) triceps on high pulley (Star Trac, USA), and (4) biceps curl on high pulley (Star Trac, USA). A 30-s interval was used between antagonistic exercises.

Muscle Strength Testing Protocols

Two groups were created through a random drawing of lots. One group began with a set using the MT, followed by a set using the MAA two hours later. The other group followed the opposite sequence, starting with the MAA method and then performing the MT method after two hours. At the end, a comparison was made between the extensor chair and biceps curl exercises. The exercises were performed with a full range of motion, including three minutes of recovery, and the speed of execution was not controlled.

Performing Muscle Strength Exercises

The biceps curl test on the low pulley began with the subject standing in front of the machine, holding the bar in a supine grip. The movement started with the concentric phase, flexing the forearm, and then returned to the starting position during the eccentric phase. The triceps test on the high pulley also began from a standing position in front of the machine, with hands on the handle and elbows close to the body. It started with the concentric phase, extending the forearm, and returned to the starting position in the eccentric phase.

The test on the flexor table started with the individual in a prone position on the machine, hands placed on the handholds, legs extended, and ankles secured under the supports. The movement began with the concentric phase, involving simultaneous flexion of the legs to attempt to touch the buttocks with the heels, followed by returning to the starting position in the eccentric phase. In the extensor chair test, participants began in a seated position with their knees flexed. They were instructed not to move their hips or lean forward. The execution began with the concentric phase, extending the knees fully and then returning to the initial position during the eccentric phase.

Signal Acquisition and Processing

For the qualitative measurement of skeletal muscle action potential, we used a Miotool 200 USB EMG device (Miotec, Porto Alegre, Brazil) featuring a four-channel data acquisition system with 14-bit resolution. Each channel had an acquisition rate of 2000 samples per second and a gain of 100. A bandpass filter was applied with a pass range of 20–500 Hz, along with six notch filters centered at 60 Hz and its harmonics up to 480 Hz. The normalized root mean square (RMS) value was then calculated, emphasizing the signal peaks to create the signal envelope. From the filtered signal, the power spectrum was derived using the fast Fourier transform, and the Fmed of the EMG signal was obtained.

In accordance with the recommendations of SENIAN (Stegeman & Hermens, 2007), it was essential to clean and abrade the skin's surface prior to data collection. Subsequently, 20-mm-wide and 10-mm-thick Meditrace 200 surface electrodes were positioned to record the electrical activity of the muscles being analyzed.

During extensor exercises, electrodes were placed on the rectus femoris, with a reference electrode positioned on the patella. For the biceps brachii exercise, the electrodes were placed on the long part, and the reference electrode was placed on the ulna. In both cases, the electrodes were positioned on the left side.

Statistical Analysis

The Shapiro–Wilks test was performed to assess the normality of distribution. Post hoc power analysis (1 - beta error level) was performed to determine the effect size using G*Power software version 3.1.9.2 (University Kiel, Germany). The statistical analysis comprised both descriptive and inferential components. Descriptive statistics were used to define the group's profile, presented as mean, standard error, standard deviation, and 95% confidence interval (95% CI). The inferential analysis involved making inferences based on the sample distribution, using Student's t-test for dependent samples to evaluate the differences between the means of Fmed for direct biceps curl and extension chair exercises across various training methods for each subject. A significance level of $\alpha = 0.05$ was established for all statistical tests. All data were analyzed using Matlab version 2020.b (The MathWorks, USA).

Results

Table 1 presents the physical and anthropometric characteristics of the volunteer group. All variables followed a Gaussian distribution ($p \geq 0.05$). The power level (1 - beta error) was calculated at 0.95, indicating a large effect size.

Table 1 Anthropometric and physical characteristics of the subjects

Variables	Mean $\pm$ SD	95% CI	P-value
Age (years)	24.8 $\pm$ 5.8	21.0–28.5	0.10
Height (cm)	177.1 $\pm$ 5.2	173.8–180.5	0.34
Body mass (kg)	85.3 $\pm$ 11.9	77.7–92.8	0.20
Body fat (%)	22.2 $\pm$ 5.4	18.8–25.7	0.69

Values are presented as mean $\pm$ standard deviation (SD), with 95% confidence intervals (95% CI) and p-values from the Shapiro–Wilk test.

The Fmed values for the extension chair test with a load of 10 RM (101.6 $\pm$ 20.2 kg) were 78.1 $\pm$ 4.3 Hz (95%CI 69.7–86.5 Hz) for MT and 79.1 $\pm$ 3.4 Hz (95% CI 75.5–85.8 Hz) for MAA, with no significant difference observed ($p = 0.856$). For the direct biceps curl test at the same load of 10 RM (27.5 $\pm$ 5.1 kg), the Fmed values were 75.6 $\pm$ 0.96 Hz (95% CI 73.7–77.5 Hz) for MT and 77.0 $\pm$ 3.1 Hz (95% CI 70.9–83.2 Hz) for MAA, also showing no significant difference ($p = 0.640$). These results indicate that, within the limitations of this study, there was no detectable difference in neuromuscular fatigue, as measured by Fmed, between the MT and MAA training methods for the exercises tested.

Discussion

This study investigated the effect of the agonist/antagonist method (MAA) and the traditional method (MT) of strength training on median frequency (Fmed) of the electromyography (EMG) signal in experienced male strength trainers. Contrary to the hypothesis that MAA would elicit different neuromuscular responses, no significant differences in Fmed were observed between MAA and MT during either the extension chair exercise or the biceps curl exercise. Specifically, Fmed values for both exercises showed no statistically significant difference between the two training methods for both exercises.

Paz et al. (2014) performed a study involving 10 trained volunteers that compared MT with three sets in the vertical bench press exercise followed by three sets in the open row. In the MAA protocol, participants performed three sets in pairs between the bench press and the open row, with a two-minute rest interval between sets. Their findings suggested that MAA was more effective than MT in assessing training volume. In contrast, this study evaluated a single series at a 10RM for the extensor chair and biceps curl exercises, revealing no significant differences between the assessed methods.

The MAA involves performing two consecutive exercises without rest, using two opposing muscles (Gomes et al., 2014; Nobre et al., 2012). This approach has been shown to be more effective for strength and hypertrophy gains compared to the MT (Nascimento et al., 2019; Peuckert & Feldmann, 2017; Paz et al., 2014; Robbins et al., 2010) and for enhancing athletic performance (Anjum et al., 2016; Nelson et al., 1986) or incorporate antagonist stretching for improved exercise repetition (Miranda et al., 2021). It is important to note that the abovementioned studies focused on the performance of maximum repetitions in the exercises, which may lead to different mechanical mechanisms. In contrast, this study examined the energy of the power spectrum of neuromuscular action to explore reciprocal inhibition (Geertsens et al., 2008; Crone, 1993) through the process of physiological muscle fatigue (Bandeira et al., 2009).

Several studies (Mason et al., 2019; Dal Maso et al., 2017) highlight the complex neural adaptations that occur during strength training, involving both agonist and antagonist muscle activity. This indicates that although MAA training may engage different neural pathways, it does not necessarily lead to significant changes in the Fmed of the EMG signal, especially in experienced individuals (Hortobágyi et al., 2022).

Zhao et al. (2020) examined the effects of MAA on power output and fatigue. While these studies demonstrate variations in performance, they do not explore the details of EMG frequency. This suggests that the training method influences performance but does not necessarily result in substantial changes in the specific aspects of the EMG signal being analyzed.

However, while several studies (Paz et al., 2017; Robbins et al., 2010; Beck et al., 2007) have identified differences in EMG activity between MAA and MT, other aspects of the EMG signal may also vary. In contrast, this study suggests that there may be no significant differences in Fmed.

Although the findings may be relevant to the specific parameters examined, the broader implications warrant further exploration, considering the complexity of neural adaptation and the potential for individual variability. Additional research is essential to fully understand the nuances of MAA and its impact on neuromuscular function.

Conclusions

The results indicated no significant differences in the Fmed behavior of the EMG signal between the MAA and MT for both upper and lower limb exercises among men experienced in strength training. The lack of a significant difference in Fmed doesn't negate the potential benefits of MAA reported elsewhere, but highlights the complexity of neuromuscular responses to training.

This research emphasizes the need for further investigation into the relationship between training methods, specific EMG parameters and physiological adaptations. Future studies should investigate different training protocols such as number of sets, rest periods and repetitions, additional EMG parameters and individual variability. Optimization of strength training programmers requires consideration of specific training goals and assessment metrics, with approaches tailored to individual needs.

Conflict of interest

The authors declare that they have no conflicts of interest.

Author contributions

Wollner Materko and Wilson Lobato Souza were the principal investigators, contributing to the study design, performing the work, analyzing the data, and drafting the manuscript. Caio Cesar dos Reis Façanha, Sávio Andrei Medeiros Miranda, Thiago Henrique Lobato Bezerra, Gizelly Coelho Guedes, and Dilson Rodrigues Belfort contributed to the study design, informed consent, and interpretation of results. All authors reviewed and approved the final manuscript and are responsible for all aspects of the work.

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