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Original Research

Effect of Static Stretching on Agonists, Antagonists, and Agonist-Antagonist Combination on Total Training Volume

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ABSTRACT

***International Journal of Exercise Science* 16(4): 665-675, 2023.** The purpose of this study was to examine the effects of static stretching (SS) of agonists and antagonists between sets on the total training volume (TTV) performed across multiple sets for the leg extension exercise. Twelve male subjects with experience in resistance training (RT) participated in this study. Subjects performed 10 repetition maximum (10RM) test and retest trials for the leg extension exercise. Four different protocols were randomly applied as follows: quadriceps stretching (AG); hamstrings stretching (AN); quadriceps and hamstrings stretching (AGN); and traditional control without stretching (TR). Significant differences ($p \leq 0.05$) were observed in the TTV between the AG (4855.42 ± 1279.38 kg) and AN (6002.08 ± 1805.18 kg), AGN (5977.50 ± 1778.49 kg), and TR (6206.04 ± 1796.15 kg) protocols. These results suggest that when practicing inter-set SS, it should be done for antagonist rather than agonist muscles when the intent is to maximize TTV.

KEY WORDS: Strength training, quadriceps, hamstring, elongation, leg extension machine

INTRODUCTION

The total training volume (TTV) in resistance training (RT) can be defined by the product of the load, the number of sets, and the number of repetitions in each set (14). The increase in TTV leads to a higher time under tension, which will result in neuromechanical and metabolic stimuli that may improve adaptations to RT (8). Thus, it is interesting to find strategies that can be performed during training and that can increase TTV. There is evidence that some activities performed between sets (inter-set) can improve performance in the number of repetitions and, consequently, increase TTV (13). In this context, stretching exercises are an option, as they are simple, easy to perform, and do not need implements.

However, some authors have found negative effects on TTV in RT preceded by stretching of agonist muscles (10, 19, 34). Conversely, some authors have found positive effects in performing stretching for antagonistic muscles, specifically static stretching (SS), in muscle performance of the agonists (21, 25).

Despite studies that reported acute negative effects of SS on agonists when preceding RT, the results appear to be different when performed during the inter-set interval. In a recent systematic review, the authors reported that inter-set SS showed no significant difference in relation to a protocol without stretching (13). In the same study, the authors reported that inter-set SS for the antagonistic muscles was effective to increase TTV in RT. Moreover, few studies have been conducted combining SS for the agonists and antagonists before performing the leg extension exercise (20, 34).

To the authors knowledge, no studies have compared the effects of SS on agonist and antagonist muscles, or the combination of stretching both specifically during the inter-set rest interval. Therefore, the purpose of the present study was to examine the effect of SS protocols on agonists (AG), antagonists (AN), agonist-antagonist combination (AGN), and traditional passive control (TR) on TTV in the leg extension exercise. Based on the current literature, we hypothesized that there will be a significant loss in TTV in the AG condition and a significant gain in TTV for the AN and AGN conditions versus the TR.

METHODS

Participants

Twelve male subjects (30.8 ± 4.8 years; 80.4 ± 10.9 kg; 176.8 ± 4.7 cm) with experience in RT were selected to participate in this study. The sample size provided a power of 85% and an estimated effect size of 0.25; Type I error probability of 80%; correction between repeated measures of 0.80; and correction of non-sphericity of 1.0 (BECK, 2013). Before participating in this study, subjects had performed an average of three weekly RT sessions, lasting approximately 1 hour with 10 and 15 repetition maximum loads, and 1-3 min. passive rest intervals between sets for the preceding 6 months. All subjects completed the PAR-Q and signed a consent form before participating in the present study, in accordance with the Declaration of Helsinki. All the principles that guide ethics in research involving human subjects were observed, following Resolution No. 466 of 2012/CONEP-MS. The procedures were approved by the Institutional Human Experimental Committee at the Federal University of Rio de Janeiro (CAA 08657113.0.0000.5257). This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (18). Subjects who reported musculoskeletal injuries or clinical conditions that could be aggravated by experimental procedures were excluded from the study. The subjects were encouraged to hydrate and maintain eating patterns throughout the study and were instructed not to perform intense physical activities 48 hours before each session. All selected subjects completed the study.

Protocol
This study conducted a randomized, counterbalanced, cross-over, and non-blind design. Six testing sessions were carried out over non-consecutive days. During the first two sessions, subjects performed 10 repetition maximum (10RM) test and retest trials for the leg extension exercise, with an interval of at least 48 hours between sessions. In the subsequent sessions, four different protocols were randomly applied as follows: quadriceps stretching (AG); hamstrings stretching (AN); quadriceps and hamstrings stretching (AGN); and traditional control without stretching (TR).

All protocols consisted of four leg extension sets performed for maximal repetitions with a 10RM load and with 2 minutes rest intervals between sets. The volunteers performed the static stretching protocols between all sets, with the exception of the TR protocol.

Protocol 1: The initial load was selected according to the load that each individual used in their routine training. The value of the 10RM test was collected during the process, which consisted of two to five attempts, adding to each new attempt the load available on the machine, with an interval of five minutes between each attempt. The test was interrupted when the subject was unable to perform the movement properly and/or reached exhaustion (34). To reduce the margin of error during the test, the following strategies were adopted: 1) Standardized instructions were offered before the test so that the subject was aware of the whole routine that involved data collection; 2) The subject was instructed on exercise technique; 3) The evaluator was aware of the position adopted by the subject at the time of the test, as small variations in the positioning of the joints involved in the movement could trigger other muscles, leading to erroneous interpretations of the scores obtained; verbal encouragement was given to maintain a high level of motivation. The individuals were instructed not to ingest any stimulating substance (caffeine or alcohol) and not to perform physical activity on the day before or on the day of the tests (15, 17).

The stretching protocols were adapted from Sá *et al*. (2015) (24). Protocol 1 - Quadriceps stretching (AG): For the quadriceps stretch, the subject was positioned on a mat on the floor, in a lateral position, with one knee flexed, and the evaluator slowly pressed the subject's ankles towards the hips to the point of discomfort. Each stretch lasted 20 seconds and was performed twice on each limb, with no interval between sets, totaling 80 seconds for the anterior thigh muscles (quadriceps) unilaterally. The remaining time of 40 seconds served as a margin for positioning the subject in the leg extension machine and changing the position for stretching. Then, the subject performed the maximum number of repetitions for the leg extension.

Protocol 2: Hamstring stretching (AN): For the hamstrings stretch, the subject was seated on a mat on the floor, with one leg extended in front of the body and the other comfortably retracted, thus performing trunk flexion. The standing examiner positioned behind the subject, with arms extended, exerted moderate pressure on the dorsal region of the subject. Each stretch lasted 20 seconds and was performed twice on each limb totaling 80 seconds, up to the point of discomfort, for the posterior thigh muscles (hamstrings) unilaterally. The remaining time of 40 seconds served as a margin for positioning the subject in the leg extension machine and changing the position for stretching. Then, the subject performed the maximum number of repetitions for the leg extension.

Protocol 3: Quadriceps/hamstring stretching (AGN): For the quadriceps stretch, the subject was positioned on a mat on the floor, in a lateral position, with one knee flexed, and the evaluator slowly pressed the subject's ankles towards the hips to the point of discomfort. For the hamstrings stretch, the subject was seated on a mat on the floor, with one leg extended in front, the other led comfortably retracted and performed a trunk flexion. The standing examiner positioned behind the subject, with arms extended, exerted moderate pressure on the dorsal region of the subject. Each stretching exercise lasted 20 seconds and was performed once on each musculature of each limb, totaling 80 seconds, up to the point of discomfort, for anterior (quadriceps) and posterior thigh (hamstring) muscles, unilaterally. The subject had 20 seconds to position himself for stretching after the set and 20 seconds to position himself on the machine for the subsequent set. Then, the subject performed the maximum number of repetitions for the leg extension.

Protocol 4: Traditional protocol (TR): In this protocol, the subject performed the maximum number of repetitions for the leg extension, but without performing inter-set stretching.

Statistical Analysis
The statistical treatment was performed using SPSS software version 21.0. Initially, the Shapiro-Wilk normality and homoscedasticity test (Barlett criterion) were performed. All variables had a normal distribution. One-way ANOVA with repeated measures was applied to verify the interaction between protocols in TTV. A repeated measures ANOVA 4 (protocols) x 4 (set) was used to compare time effect in AG, AN, AGN and TR in each set (set 1, set 2, set 3 and set 4). Bonferroni's *post hocs* were used for inferential analysis when a significant F-value was achieved. Effect sizes (ES) in absolute differences in raw values of the variables using the standardized difference based on Glass's delta units by means (15). The level of statistical significance was set at $p \leq 0.05$.

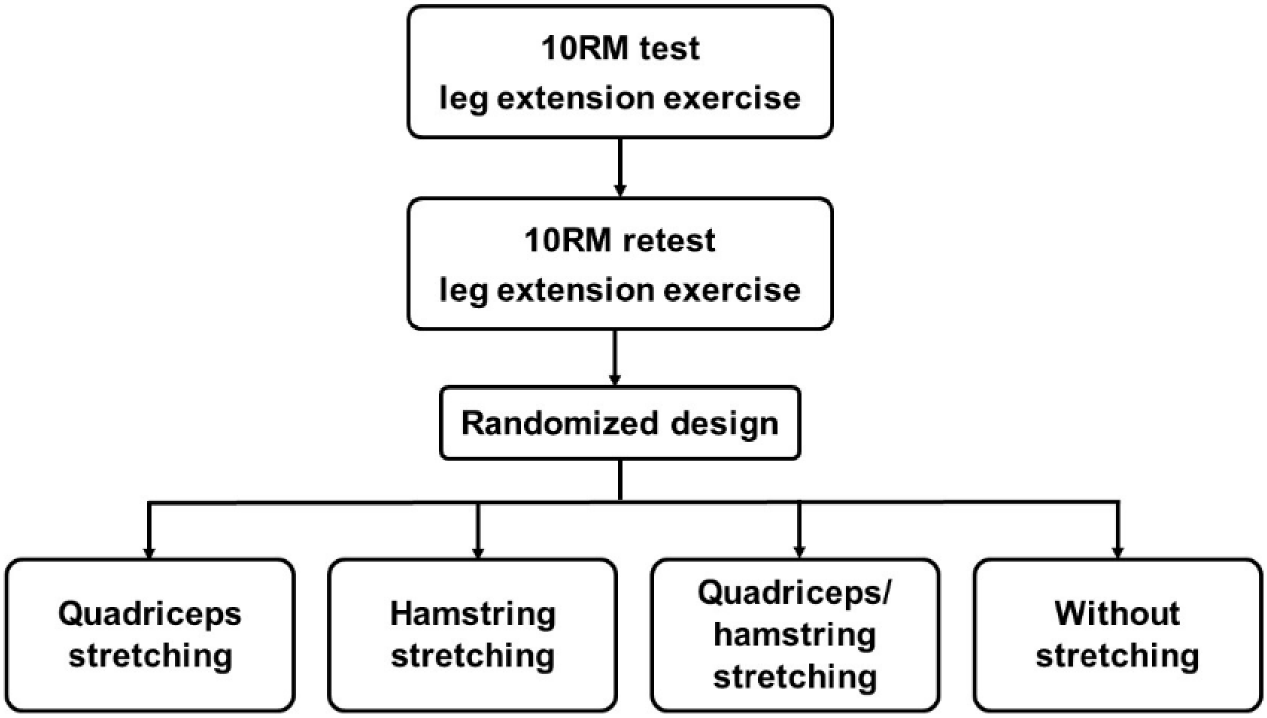

Figure 1. Study design.

RESULTS

Table 1 shows the mean and standard deviation values for the number of repetitions in each protocol and the significant differences in the number of repetitions between the protocols, in each set, in relation to the AG protocol [F (3.99, 43.93) = 1.773; p = 0.151]; and in the sets within each protocol compared to set 1 [F (1.21, 13.30) = 10.473; p = 0.005].

Protocols: AG set 1 vs set 2 (p > 0.05; IC95% - 1.024, 2.357; ES = - 1.72), set 1 vs set 3 (p = 0.035; IC95% 0.147, 4.853; ES = - 6.41), set 1 vs set 4 (p = 0.024; IC95% 0.397, 6.436; ES = - 8.76); AN set 1 vs set 2 (p > 0.05; IC95% - 2.359, 2.026; ES = 0.10), set 1 vs set 3 (p > 0.05; IC95% - 1.810, 4.144; ES = - 0.68), set 1 vs set 4 (p = 0.710; IC95% - 1.788, 5.788; ES = - 1.17); AGN set 1 vs set 2 (p = 0.820; IC95% - 1.164, 3.497; ES = - 0.50), set 1 vs set 3 (p = 0.072; IC95% - 0.196, 5.862; ES = - 1.21); set 1 vs set 4 (p = 0.016; IC95% 0.654, 7.013; ES = - 1.63); TR set 1 vs set 2 (p > 0.05; IC95% - 1.766, 1.766; ES = 0,00), set 1 vs set 3 (p > 0.05; IC95% - 1.962, 4.128; ES = - 0.70), set 1 vs set 4 (p = 0.335; IC95% - 1.086, 5.419; ES = - 1.39).

Set 1 protocol AG vs AN (p = 0.212; IC95% - 2.532, 0.365; ES = 2.77), AG vs AGN (p = 0.029; IC95% - 4.307, - 0.193; ES = 5.77), AG vs TR (p = 0.033; IC95% - 2.896, - 0.104; ES = 3.85); Set 2 protocol AG vs AN (p = 0.001; IC95% - 2.995, - 0.838; ES = 1.11), AG vs AGN (p = 0.011; IC95% - 3.125, - 0.375; ES = 1.01), AG vs TR (p < 0.001; IC95% - 2.940, - 1.394; ES = 1.25); Set 3 protocol AG vs AN (p = 0.017; IC95% - 4.448, - 0.385; ES = 1.01), AG vs AGN (p = 0.100; IC95% - 4.096, 0.263; ES = 0.80), AG vs TR (p = 0.007; IC95% - 5.060, - 0.773; ES = 1.22); Set 4 protocol AG vs AN (p =

0.010; IC95% - 4.455, - 0.545; ES = 0.79), AG vs AGN (p = 0.215; IC95% - 4.294, 0.627; ES = 0.58), AG vs TR (p = 0.002; IC95% - 4.522, - 0.978; ES = 0.87).

Table 1. Descriptive values of the number of repetitions between protocols and sets.

	AG	AN	AGN	TR
Set 1	10.17 ± 0.39	11.25 ± 1.71	12.42 ± 2.35*	11.67 ± 1.56*
Set 2	9.50 ± 1.73	11.42 ± 2.31*	11.25 ± 2.56*	11.67 ± 2.06*
Set 3	7.67 ± 2.39#	10.08 ± 3.06*	9.58 ± 3.18	10.58 ± 3.37*
Set 4	6.75 ± 3.17#	9.25 ± 4.16*	8.58 ± 3.53#	9.5 ± 3.80*

AG = quadriceps stretching protocol; AN = hamstring stretching protocol; AGN = quadriceps and hamstring stretching protocol; TR = traditional protocol (without stretching) ($p \leq 0.05$). *Significant difference in relation to the AG protocol; #Significant difference compared to set 1 ($p \leq 0.05$).

There was a significant effect between protocols in the TTV [F (3,33) = 18.896; $p \leq 0.001$]. When verifying the interaction between protocols (Bonferroni's *post hoc*), there was a significant difference between the agonist stretching protocol versus the antagonists (p = 0.003; IC95% - 1910.30, - 383.03; ES = 0.90), agonist-antagonist (p = 0.007; IC95% - 1954.39, - 289.76; ES = 0.88), and traditional protocol (p < 0.001; - 2009.79, - 691.46; ES = 1.06) (see Figure 2).

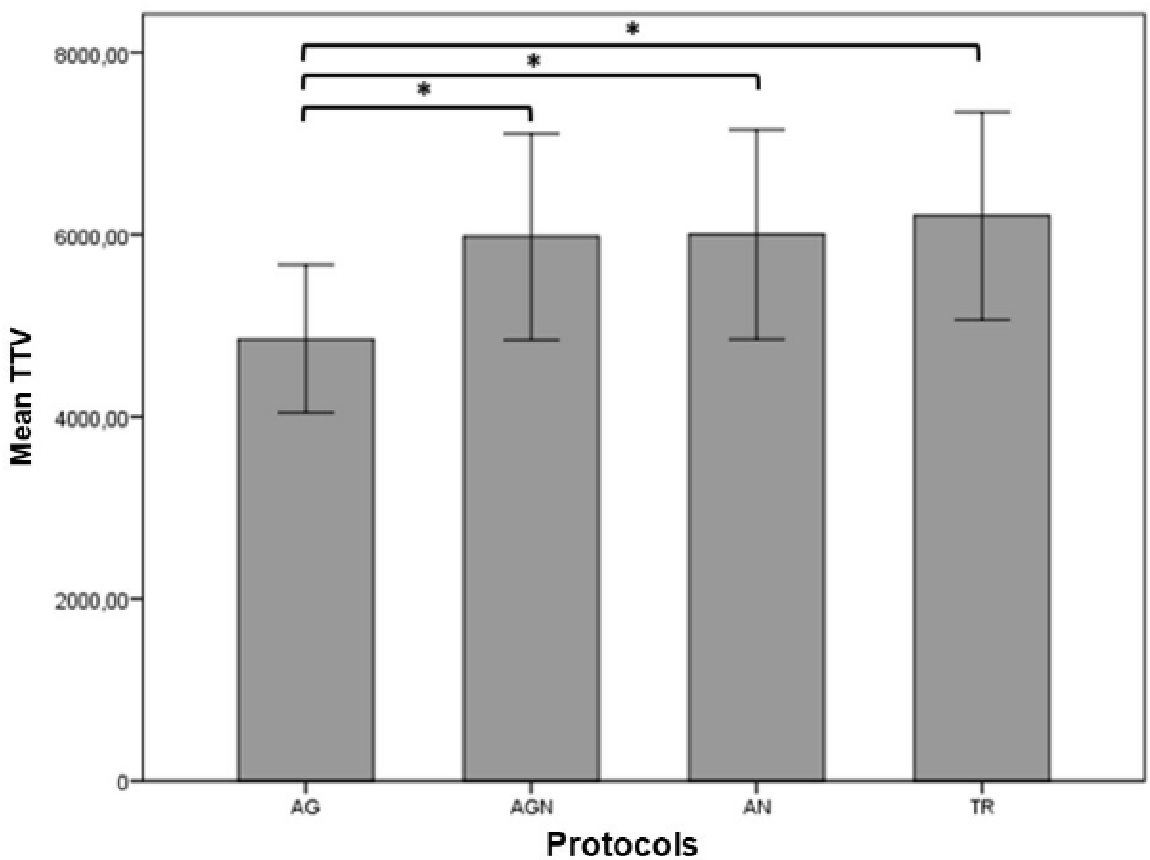

Figure 2. Total training volume (TTV) in each protocol.

DISCUSSION

The main finding of the present study was the significant decrease in TTV for the AG protocol (4855.42 ± 1279.38 kg) in relation to the AN (6002.08 ± 1805.18 kg), AGN (5977.50 ± 1778.49 kg), and TR (6206.04 ± 1796.15 kg) protocols. Furthermore, for protocols that involved stretching the antagonist musculature (AN and AGN), the TTV wasn't significantly different from the TR protocol.

There is little evidence for the efficacy of SS to improve (27, 32) or have a neutral effect on influence strength performance (16). Conversely, there is a lot of evidence that SS before or during RT can decrease strength and power performance (3, 29, 31, 34). The scientific literature reports that the acute decrease in muscle force output when preceded by SS can be due to mechanical or neural factors, such as a decrease in motor unit activation, greater compliance in musculotendinous units, and changes in the length-tension curve of muscle fibers (3, 29). Therefore, it would be normal to think that, with evidence of impairments in strength and power performance caused by SS in agonist muscles before exercise, this strategy would also result in lower TTV. Despite this, some authors theorized that performing SS in the interval between sets could assist in the recovery process and improve strength performance (7, 28). The present study refutes this hypothesis, as inter-set SS significantly decreased TTV (Figure 1).

This result contradicts previous studies carried out in individuals with experience in RT, where there were no significant differences in TTV when stretching agonists versus non-stretching protocols (1, 6, 9). However, Arazi *et al*. (2016) and García-Lópes *et al*. (2010) studies were performed involving multi-articular exercises, which may explain the difference in the result. The relationship between the effects of SS on agonist muscles seems to be dependent on the muscle group and more evident in uni-articular movements (24, 34).

If SS is applied between sets for the agonist muscle, there appears to be a loss in TTV for the leg extension. However, the result of this study shows that the same does not occur if SS is applied to the antagonist muscles between sets (Figure 2). The pattern in repetitions throughout the sets was similar between the AN and TR protocols (Table 1).

Corroborating these findings, a study similar to the present study was recently carried out comparing the inter-set stretching of hamstrings versus a protocol without stretching on the TTV for the leg extension exercise (30). Despite the 20RM load, the authors also found no significant differences between the antagonist stretching protocol versus a non-stretching protocol on the number of repetitions and, consequently, in the TTV for the leg extension exercise (uni-articular).

Nevertheless, in other studies, also with individuals with experience in RT, significant increases in TTV were found when performing inter-set SS for the antagonistic muscles versus non-stretching protocols (15, 22). However, in these studies, the muscular work was performed in multi-articular exercises, which were the seated row (15) and wide-grip cable row exercise (22).

It seems that the strategy of stretching the antagonist muscles could improve the strength performance of agonists by decreasing the effectiveness of antagonist actions(25). Indeed, the strength produced in the execution of a movement depends on the relationship between the action promoted by the agonist muscles and the braking action of the antagonist muscles (2, 4). In other words, the net motive force represents the ratio of agonist to antagonist co-activation (26). This relationship is more evident in the execution of a fast movement, where the action of the agonist muscle is limited by the braking action of the antagonist muscle (11, 33).

Therefore, strategies to decrease the activation of antagonists could improve the net force output from the agonists. The scientific literature indicates that SS could decrease the activation of the antagonists (10, 12) and neural factors (23). Although the literature indicates that significant strength losses occur in exercises with SS above 60 seconds (5), 2 sets of 20 seconds as in the current study, appeared to promote significant decreases in TTV for AG protocol, but less so in the AGN and AN protocols.

Contrary to the results of the present study, previous studies have found that stretching the agonist and antagonist muscles in combination caused an acute decrease in muscle performance(20, 34). However, the sequence of the AG/AN combination was different. While in this study the SS order was quadriceps/hamstrings, in the other studies the order was hamstrings/quadriceps, with the posterior thigh muscles being the agonist in the knee flexion test. Either way, there appear to be impairments in strength performance preceded by combined SS of AG/AN, but only when the hamstrings were the agonists muscles. This may be due to differences in the capacity of strength production between these muscle groups(35). Thus, hamstring stretching immediately after quadriceps stretching seems to provide a protective effect against the deleterious effects of agonist SS on TTV.

The present study had the limitation of not having controlled the individuals' levels of flexibility. In theory, less flexible individuals could benefit more from the effects of SS. Anyway, the present study shows that performing inter-set SS on the agonist, in 2 sets of 20 seconds on each limb, was sufficient to cause significant losses in the TTV in the agonist muscle during a leg extension However, performing the same protocol on the antagonist muscles or agonist and antagonist combination did not influence the results in relation to the traditional passive control condition. SS is very efficient for developing flexibility (5). Therefore, individuals who wish to include the inter-set SS, making better use of the training time while also training flexibility during RT, should perform the stretching between sets for the antagonistic muscles. Another possible study limitation was the same researchers who performed the static stretching protocols also participated in the maximal repetitions test. Besides, it's worth mentioning that's impossible to blind a subject to the reality that they are performing, or not, static stretching.

Movement complexity (single or multi-articular), the interval between sets, time under stretching, and the order of the stretched muscles in the AG/AN combination are some of the factors that can interfere with the SS effects on muscle performance. Thus, there are still many scientific gaps to be filled in relation to the SS protocols in agonists, antagonists, and agonist and antagonist combination and their effects on TTV in RT.

The novel finding of the present study is performing SS on agonist muscles (quadriceps) between sets caused significant reductions in the TTV for the leg extension exercise versus the traditional passive rest interval, the stretching of antagonists (hamstrings), and the combination of agonist and antagonist (quadriceps/hamstrings). These results suggest that when practicing inter-set SS, it should be done for antagonist rather than agonist muscles when the intent is to maximize TTV.

These findings may be important for future research about the effects of SS in TTV. Besides, coaches and practitioners who need to develop strength and flexibility, can save training time by performing inter-set SS on the antagonist muscles in strength training, without impairment in TTV**.**

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