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# AN ELECTROMYOGRAPHIC ANALYSIS OF COMBINING WEIGHTS AND ELASTIC TUBES AS A METHOD OF RESISTANCE FOR EXERCISE

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## Abstract

The study aimed to compare the effects of elastic and weight resistance exercise on muscular activation patterns. Twenty-one moderately active males (age=25±8) performed ten bicep curls and leg extensions with weights (W), an equivalent elastic resistance (T) and a combined condition (TW) of half elastic tension and half weight resistance. Muscular activations of the biceps, triceps, rectus femoris, vastus medialis and lateralis were recorded with Trigno wireless electrodes, joint angles were recorded with Qualisys Track Manager. Biceps total activation was highest ($p<.001$) with weights during the bicep curl due to an increased ($p\leq.007$) activation in the eccentric phase. The biceps was also active over a larger portion of the ROM under TW (110°-70° elbow angle), while W and T exhibited peak activations at mid (90°) and late (50°) stages of ROM respectively. The triceps (bicep curl) was least active ($p<.05$) with W throughout the concentric phase, as were the vastus medialis and lateralis (leg extension). Although peak and total activation were similar for most muscles in all conditions, muscular activation patterns differed between conditions indicating that TW may enhance strength gains by increasing time-under-tension, engaging agonist muscles at less advantageous lengths and increasing the recruitment of auxiliary muscles.

**Keywords from TSM list**: *Exercise*

## Introduction

The use of elastic tubes as a form of resistance has become widely implemented for both rehabilitation and performance training as an alternative to isotonic training with weights. Direct comparisons of muscular demands and training efficacy of the two methods are challenging due to variations in technique, anatomy and positioning of load. As such, analysis of muscle activation through electromyography provides an accessible and comparable measure of direct influence on activation of key musculature throughout the range of motion (ROM). Previous research comparing electromyographic (EMG) responses during elastic resistance to isotonic resistance methods has provided the general understanding that both methods can elicit comparable magnitudes of peak and total EMG[1-5], with some studies demonstrating that elastic resistance typically elicits greater muscular activation at latter stages of movement compared to weight resistance[1,3]. This is primarily due to differences in mechanical loading of the methods of resistance, where elastic tension increases proportionally with the stretch of the material, therefore increasing throughout ROM, compared to the constant loading of weights, influenced only by relative alignment of the load and the supporting musculature around the joint of interest.

Elastic resistance is suggested to provide a synergistic effect when combined with free weights[6,7], eliciting higher levels of muscular activation throughout the entire ROM. There is, however, a dearth of research investigating this assumption. Ebben and Jensen[8] investigated the effects of substituting 10% of weight load with elastic resistance on muscular activation during a back squat, compared to using only weights. The authors found no differences in integrated EMG or ground reaction forces between the resistance methods and argued that there would be no additional benefits to combining the methods for strength training. However, in a subsequent intervention study on back squats and bench presses, Anderson et al.[9] found that seven weeks of training with 80% weight load and 20% elastic tension produced significantly greater improvements in 1 repetition maximum

(1RM) than weight training alone. In a similar study, Bellar *et al*[10] reported that, after three weeks of bench press training, a combination of 85% weight load and 15% elastic load also provided significantly greater strength gains than weight load alone. Finally, Rhea et al[11] reported significantly greater improvements in strength and power output when combining large elastic bands (of unspecified load) with 50% 1RM weight load during squat training in comparison to weight training alone. Ebben and Jensen's[8] EMG study used a lower proportion of elastic resistance than the three interventions[9-11], which may explain the lack in significant difference in the former. Nonetheless, the apparently conflicting findings reported by the electromyographic study[8] and the three intervention studies[9-11] emphasize the importance of considering muscular activation patterns, joint specificity and muscle recruitment patterns when comparing different resistance methods.

It was theorised that the greater improvements in the combined condition were due to an increased elastic tension at joint angles that are generally more advantageous with weight resistance[10] and due to an alteration in muscle recruitment patterns caused by the addition of elastic resistance[9]. Ebben and Jensen[8], however, only reported total muscular activation, which does not give insight to the magnitude of activation occurring at specific phases of the ROM. The authors' speculations were later supported by electromyographic research on resistance training[1,3], where increased muscular activation was observed at latter stages of movement with elastic resistance. The current literature, however, lacks studies on the specific patterns of muscular activation generated by combining the two resistance methods, which would provide a direct measurement of instantaneous muscle function through exercise rather than the effects of repeated exercise. In order to gain appropriate understanding for designing effective training programmes, it is important to consider the impact of substituting a portion of weight load with elastic tension on muscular activation patterns throughout the ROM. Considering that the combination of the two resistance methods enhances strength and power gains[9-11] despite eliciting equal total EMG values[8], it is hypothesised that the explanation may lie in a difference of muscle activation at specific joint angles. This study, therefore, aims to provide an illustration of muscular activation patterns elicited by combining elastic and weight resistance in order to gain a better understanding of how variable resistances impact strength adaptations. Bicep curls and leg extensions were selected due to being popular choices of exercise with elastic training, and due to their differing techniques and direction of applied load.

## Methodology

### *Participants*

Twenty-one recreationally active males (age= 25 ± 8 years, stature= 179 ± 7 cm, mass= 77 ± 13 kg) were recruited for the study on a voluntary basis. Before testing, all participants signed an informed consent and physical activity readiness questionnaire (PAR-Q). The study was approved by the local institutional ethics committee, in line with the principles of the declaration of Helsinki.

### *Conditions*

Pilot testing for this study determined that an angular velocity of 120°/s was most consistent with the average self-determined exercising pace, as such all conditions in this study were performed at an average angular velocity of 120°/s and all tubes were individually prepared with a 10% reduction in initial length to ensure that the load of the tube equalled the load of the weights at mid ROM for both exercises. Having considered that peak muscle activation tends to occur at opposing segments of the ROM with weights and tubes, about 50% of each load was implemented in the combined condition to test whether a similar proportion of each load would provide a more uniform activation throughout the ROM. The three resistance methods consisted of 6kg weights (W), Silver Thera-band® tubes (T), equivalent to 6kg at 100% stretch (mid ROM),[12] and a combined condition (TW) consisting of 47% weight and 53% elastic resistance by using a 2.8Kg weight and a blue Thera-Band® tube, equivalent to 3.2kg at 100% stretch,[12] which coincided with mid ROM for both exercises.

### *Isokinetic Testing*

Participants warmed up with dynamic exercise for five minutes and performed three isometric maximal voluntary contractions (MVC) on a Biodex Dynamometer (Biodex Corporation, NY, USA) for the purpose of normalisation of the EMG signal. Data for the biceps and triceps brachii were obtained by attempting to flex and extend the arm with the elbow angle fixed at 90° and a supine forearm; data for the leg muscles were obtained by attempting to flex and extend the knee with a hip angle of 90° and a knee angle of 75°. For testing, participants performed a set of ten repetitions for each condition in random order. Three minutes resting time were allowed between sets to avoid fatigue. Movement velocity was controlled with a video of every exercise performed at the required rate; the participants were required to practice mirroring the video without resistance prior to the trials to become accustomed to the speed of movement and the video was then left running on loop throughout testing as a reference for movement velocity.

### *Electromyography*

Prior to commencing the tests, the participant’s skin was prepared, consisting of cleaning, shaving and light abrasion, in order to reduce impedance and improve the muscular signal. Trigno surface wireless electrodes (DelSys Inc., Boston, USA) with 20mm single-differential interelectrode distance were then positioned on the biceps brachii, the triceps brachii long head, rectus femoris, vastus lateralis and vastus medialis in accordance with the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines.[13] Retroreflective markers were placed on the acromion, lateral humeral epicondyle and radial styloid process to measure elbow joint angles, and between the greater trochanter, lateral epicondyle of the femur and lateral malleolus of the fibula to measure knee joint angles. Marker location was analysed through 3D motion capture (Qualisys Medical AB, Savedalen, Sweden).

EMG (mV) was recorded at 1926Hz with a band pass filter of 20-450 Hz. Raw EMG data were averaged by root mean square (RMS), with window length .125s and overlap .0625s and normalised to MVC. Joint angles were tracked using Oqus cameras through Qualisys Track Manager (Qualisys Medical AB, Savedalen, Sweden) at 231Hz. The two systems were synchronised via a trigger module (DelSys Inc., Boston, USA). Muscular activation (%MVC), and joint angle (degrees) were plotted against time as parallel subplots through EMGworks Analysis software (DelSys Inc., Boston, USA), which enabled muscle activation to be related to joint angle. Peak EMG was recorded as the mean of three RMS MVC peaks, taking the peak from the first three repetitions, the next peak from the middle four, and the last peak from the final three repetitions. Total activation was calculated as the integrated RMS EMG curve over a full set of ten repetitions, where total activation for the elastic conditions was normalised to the weight condition by reporting the former as a ratio of the latter. Muscular activation and angular velocity patterns were drawn by calculating the average EMG (%MVC) and average angular velocity (°/s) for every 20° of ROM from three repetitions of each set.

### *Statistical Analysis*

A Shapiro-Wilk test was used to determine normality using the statistics software IBM SPSS 24 (IMB SPSS Inc, Chicago, USA. A repeated measures ANOVA with Bonferroni *post-hoc* was performed for each pair of methods, with Resistance (T, W or TW) and ROM (7 levels for bicep curls, 6 levels for the leg extension) as variables. Concentric and eccentric phases were analysed with two separate ANOVAS. Peak and total activation were analysed between the three resistance methods (T, W, TW) via a repeated measures ANOVA with Bonferroni *post-hoc*. Significant difference was accepted at alpha = .05 for all statistical tests.

## Results

### *Bicep Curl*

#### *Biceps Brachii*

During the bicep curl, total biceps activation was higher (p=.001) with weights than in all other conditions (Figure 1). Peak activation (Figure 2) was equivalent in all three conditions but occurred earlier (90° elbow angle) in the weight condition, later in the elastic condition (50°) and formed a plateau (110°-70°) in the combined condition (Figure 3A). Throughout the ROM, elastic tubes and weights elicited significantly different (p<.05) levels of activation: elastic resistance elicited the lowest activation at initial stages of ROM (110-150°) and the highest activation at the end of the ROM in both the concentric (p=.04) and eccentric (p=.007) phases (Figure 3A). The combined condition elicited an activation pattern that averaged that of the other two resistances and only displayed significantly lower values (p<.05) than W in the eccentric phase.

#### *Triceps Brachii*

There were no statistical differences in total triceps activation (Figure 1), while peak activation was lowest (p=.004) with weights (Figure 2) and occurred earlier in the ROM (90°) with respect to T and TW (50°). W elicited higher activation than T at early stages of ROM and lower activation at the end of the elbow flexion (p=.03) (Figure 3B).

### *Leg Extension*

#### *Rectus Femoris*

There were no significant differences between total activation, peak activation, or muscular activation patterns of the rectus femoris under any of the three resistance methods.

#### *Vastus Medialis*

There were no significant differences between total or peak vastus medialis activation between resistance methods. T and TW elicited a higher (p<.001) activation than W throughout most of the concentric phase, while only T was significantly (p=.009) higher than W in part of the eccentric phase (Figure 4B).

### *Vastus Lateralis*

There were no significant differences in total or peak vastus lateralis activation between resistance methods. Muscular activation of the vastus lateralis (Figure 4C) was however significantly lower with weights for most of the concentric phase (p=.002); while trends are similar in the eccentric phase but without reaching statistical significance (p=.077).

## Discussion and Implications

Throughout the ROM, combining weight and elastic resistance produced magnitudes of muscular activation that averaged those of the elastic and weight resistance when used alone. In addition, the combined condition elicited muscular activation patterns that differed from those of the weight condition, more closely reflecting those elicited by the elastic condition.

### *Total Activation*

Total biceps activation was higher in the weight condition due to an increased activation in the eccentric phase, which was not observed in the elastic or combined conditions. Considering that, at equal loads, eccentric muscle action contributes to strength adaptations as much as the concentric action does,[14] in the case of the bicep curl, a training programme with weight resistance might produce greater strength increases due to a greater overall activation. This assumption, however, is not reflected in the findings reported by previous intervention studies.[9-11] In accordance with Ebben and Jensen's[8] findings, this study revealed that total muscular activation did not differ between conditions for any other muscles except for the biceps brachii. However, despite the lack of difference in total EMG activation reported here and by Ebben and Jensen[8] during a back squat, the aforementioned intervention studies all reported greater strength gains with the combined resistance method than with weights alone.[9-11] This stresses for a consideration of the impact of muscular activation patterns on strength adaptations rather than peak or total activation alone. Although reporting total activation gives some insight into the magnitude of muscular responses, it does not allow for the investigation of particular forces that might influence muscular overload at less advantageous joint angles or sarcomeric lengths, which would in turn enhance myofibrillar adaptations. In addition, it must be considered that increases in 1RM comprise of the contribution of several muscles, where the analysis of multiple components of a muscle group is also relevant in understanding the influence of resistance methods on strength adaptations. Although total activation of the three quadriceps muscles was equivalent in all conditions, muscular activation patterns of the vastus medialis and lateralis were higher ($p<.05$) throughout the concentric phase of the leg extension, suggesting a greater contribution to the movement under both the elastic and combined conditions, which would translate to greater increases in 1RM following training. This evaluation indicates that total activation of the agonist muscle is not the sole contributor to strength gains and that muscular activation at specific muscle lengths must also be taken into consideration when comparing methods of resistance.

### *Muscle Activation Patterns*

During the bicep curl, weight and elastic resistance provided similar magnitudes of peak agonist activation that occurred at early and late stages of ROM respectively, while the combined condition provided a plateau of biceps activation that lasted most of the concentric phase (Figure 3). Provided that time under tension is a key factor in producing strength adaptations,[15] it is plausible that a more extended muscular activation throughout the ROM would have contributed to the added strength gains observed in Bellar *et al*[10], Rhea et al[11] and Anderson *et al.*[9] At equal loads, greater time under tension induces greater protein synthesis than shorter activation times even at low intensities[15] (30% 1RM), therefore a resistance method (TW) that provides exertion throughout a wider portion of the ROM would be expected to produce greater strength adaptations than one that produces peak activation only at certain elbow angles (W or T). In this particular study, however, due to the variability of the elastic resistance, applied loads were not equivalent throughout the entire ROM. With the current proportions (53% T + 47% W), the combined condition provided an EMG amplitude that averaged that of the two other resistances at any point in the ROM, producing a longer activation time in the concentric phase, but never reaching the peak values elicited by either of the resistances on their own (Figure 3). Implementing higher proportions of elastic and weight resistance (i.e. 70% T + 70% W) in the combined condition would increase the muscular activation throughout the entire ROM, producing a plateau of amplitudes equivalent to those elicited by the other two resistances (T, W), hence further enhancing strength gains, although the implementation of this strategy may be limited at higher loads. Further studies could investigate the optimal combination of the two resistances through both analytical and longitudinal studies, to determine what proportion of T and W provides a plateau with equal amplitudes to those offered by either resistance, and how the increased time under tension provided by this combination might affect strength adaptations through training.

Furthermore, these findings support Behm's[7] recommendations of adding elastic resistance to weighted power training to provide muscular overload throughout the entire ROM. The addition of elastic resistance to weight training would be particularly beneficial in providing muscular exertion at phases of movement where the joint position is most advantageous with respect to gravitational forces, but where myofilament overlap is least advantageous (i.e. end of the ROM during a bicep curl or sticking point of a bench press) therefore maximising strength gains.

For the leg extension in particular, the combined condition closely reflected the muscular activation patterns and levels observed under elastic resistance alone, providing an average activation 5% higher than with weight resistance for both the vastus medialis and lateralis throughout the concentric phase (Figure 4). This suggests that, despite contributing to only half of the applied load, the elastic tension provided was sufficient to cause a destabilization of the knee joint, requiring a greater contribution of these muscles throughout the knee extension. These findings offer a possible further explanation for the enhanced strength gains reported by Anderson et al[9] and Bellar et al[10], which could also be related to improved strength in synergist muscles with combined resistances, increasing total force output and, therefore, 1RM. Due to the variability of the elastic load throughout the ROM, a training programme that combined the use of elastic and weight resistance would therefore be expected to also enhance the recruitment of synergist muscles, which is particularly desirable in proprioceptive training and joint rehabilitation. In strength training, the enhanced agonist-synergist coactivation offered by the combined resistance would also promote greater improvements in 1RM by inducing strength adaptations in both the agonist and synergist muscles.

A similar behaviour is observed for the antagonist muscle of the bicep curl. Triceps activation patterns and magnitudes in the combined condition were nearly identical to the ones provided by elastic resistance alone, with an average activation 13% higher than weights at the end of the ROM (Figure 3), further supporting the assumption that elastic tension contributes to an increased muscle recruitment by way of joint destabilization. In addition, the increasing recoil force of the tubes requires a greater recruitment of antagonist muscles to resist the joint from being extended at final stages of ROM. This indicates that combining the two methods may be as effective as elastic resistance alone in increasing antagonist muscle activation during exercise, producing adaptations that may enhance joint stability for slow isokinetic and isometric movements.[16]

### *Study Limitations*

The main limitation of this study relates to how the loads were implemented. Although the participating population was of homogenous fitness level and anthropometric measurements, implementing a same load for all participants meant that resistances did not correspond to equal percentages of their 1RM. The authors recognise the limitations of using a same load for all participants; however, due to the limited availability of resistance levels offered by the manufacturer, and to the complexity of elastic loading during dynamic exercise, it was preferable to implement the same material throughout the study for consistency. Normalising the load to 1RM could have been achieved by using tubes of varying thickness and by adjusting their initial length. However, the strain rate of the material is not linear and further varies between tubes of different thicknesses.[17] Due to this variability, if different initial lengths of each tube would have been used to account for 1RM, the loading pattern of the elastic conditions would have been modified, hence affecting muscular activation patterns. Therefore, although implementing the same load for all participants produced high variance in the data, the authors preferred to control for loading patterns for an initial assessment of how these affected muscular activation patterns throughout the ROM. Further studies with greater loads (adjusted to 1RM), and with different percentages of elastic and weight loading, may help determine the most appropriate way of using elastic resistance for strength training.

### *Perspective*

The combination of elastic and weight resistance provides muscular exertion at a wider range of muscle lengths, compared to use either method alone, offering a plateau in muscle activation that increases the time under tension of the agonist muscle, and enhances the recruitment of antagonist muscles. Combining these two forms of resistance may, therefore, contribute to greater strength gains than weight resistance alone.

## References

1. Jakobsen MD, Sundstrup E, Andersen CH, Persson R, Zebis MK, Andersen LL. Effectiveness of hamstring knee rehabilitation exercise performed in training machine vs. elastic resistance: electromyography evaluation study. American journal of physical medicine & rehabilitation. 2014;93(4):320-7.

2. Jakobsen MD, Sundstrup E, Andersen CH, Aagaard P, Andersen LL. Muscle activity during leg strengthening exercise using free weights and elastic resistance: effects of ballistic vs controlled contractions. Human movement science. 2013;32(1):65-78.

3. Aboodarda SJ, Hamid MS, Che Muhamed AM, Ibrahim F, Thompson M. Resultant muscle torque and electromyographic activity during high intensity elastic resistance and free weight exercises. European Journal of Sport Science. 2013;13(2):155-63.

4. Serner A, Jakobsen MD, Andersen LL, et al. EMG evaluation of hip adduction exercises for soccer players: implications for exercise selection in prevention and treatment of groin injuries. Br J Sports Med. 2014;48(14):1108-14.

5. Matheson JW, Kernozek TW, Fater DC, Davies GJ. Electromyographic activity and applied load during seated quadriceps exercises. Medicine and science in sports and exercise. 2001;33(10):1713-25.

6. Frost DM, Cronin J, Newton RU. A biomechanical evaluation of resistance. Sports Medicine. 2010;40(4):303-26.

7. Behm DG. An analysis of intermediate speed resistance exercises for velocity-specific strength gains. J Appl Sport Sci Res. 1991;5(1):1-5.

8. Ebben WE, Jensen RL. Electromyographic and kinetic analysis of traditional, chain, and elastic band squats. The Journal of Strength & Conditioning Research. 2002;16(4):547-50.

9. Anderson CE, Sforzo GA, Sigg JA. The effects of combining elastic and free weight resistance on strength and power in athletes. The Journal of Strength & Conditioning Research. 2008;22(2):567-74.

10. Bellar DM, Muller MD, Barkley JE, et al. The effects of combined elastic-and free-weight tension vs. free-weight tension on one-repetition maximum strength in the bench press. The Journal of Strength & Conditioning Research. 2011;25(2):459-63.

11. Rhea MR, Kenn JG, Dermody BM. Alterations in speed of squat movement and the use of accommodated resistance among college athletes training for power. The Journal of Strength & Conditioning Research. 2009;23(9):2645-50.

12. Page PA, Labbe A, Topp RV. Clinical force production of Thera-Band® elastic bands. Journal of orthopaedics, sports and physical therapy. 2000;30(1):A-48.

13. Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles 2012. www.SENIAM.org Accessed September 20, 2013.

14. Roig M, O'Brien K, Kirk G, et al. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: a systematic review with meta-analysis. British journal of sports medicine. 2009;43(8):556-68.

15. Burd NA, Andrews RJ, et al. Muscle time under tension during resistance exercise stimulates

differential muscle protein sub-fractional synthetic responses in men. The Journal of physiology. 2012;590(2):351-62.

16. Aagaard P, Simonsen EB, Andersen JL, Magnusson SP, Halkjaer-Kristensen J, Dyhre-Poulsen P. Neural inhibition during maximal eccentric and concentric quadriceps contraction: effects of resistance training. Journal of Applied Physiology. 2000;89(6):2249-57.

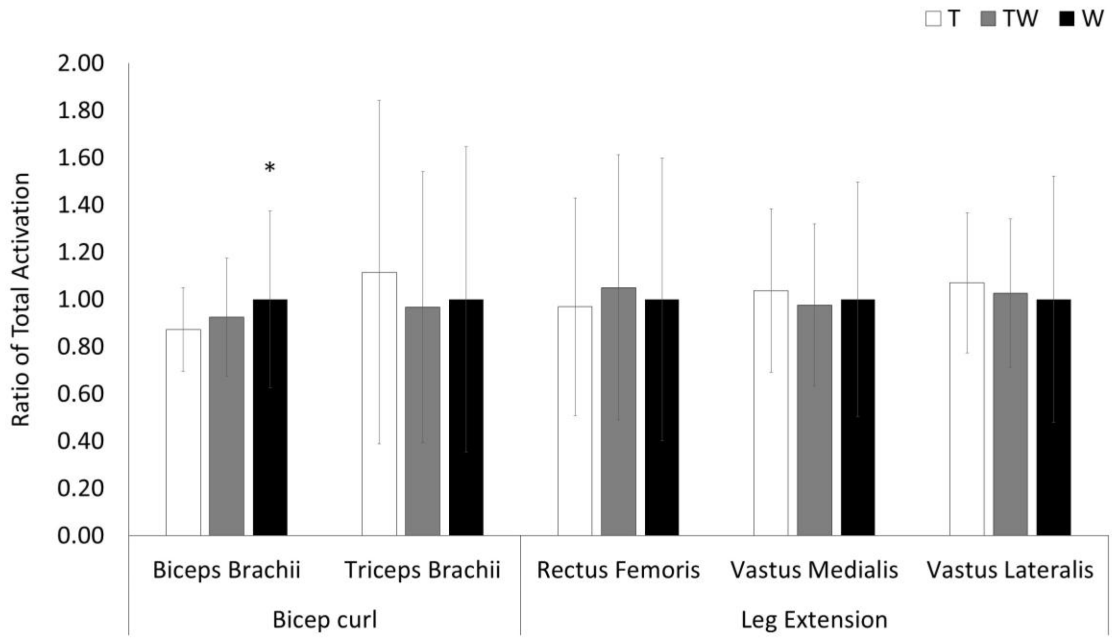
17. Santos GM, Tavares G, Gasperi GD, Bau GR. Mechanical evaluation of the resistance of elastic bands. Brazilian Journal of Physical Therapy. 2009;13(6):521-6.

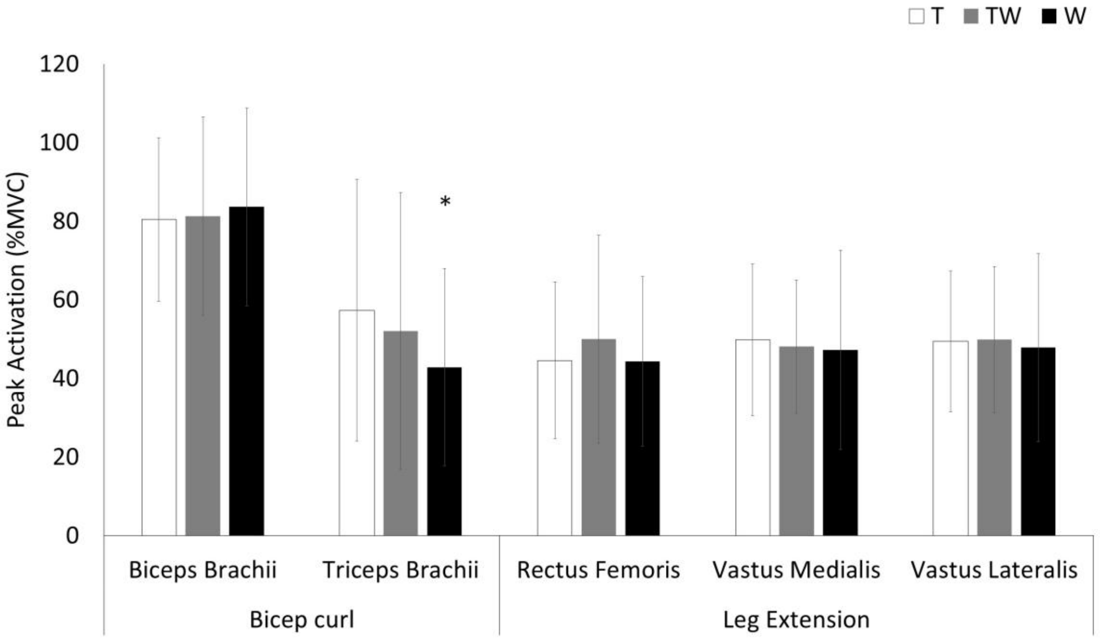
Figure 1. Mean ± SD ratio of total muscular activation when exercising with three different resistance methods: tubes (T), tubes and weights combined (TW), weights only (W). * W significantly different (p<.001) than T and TW.

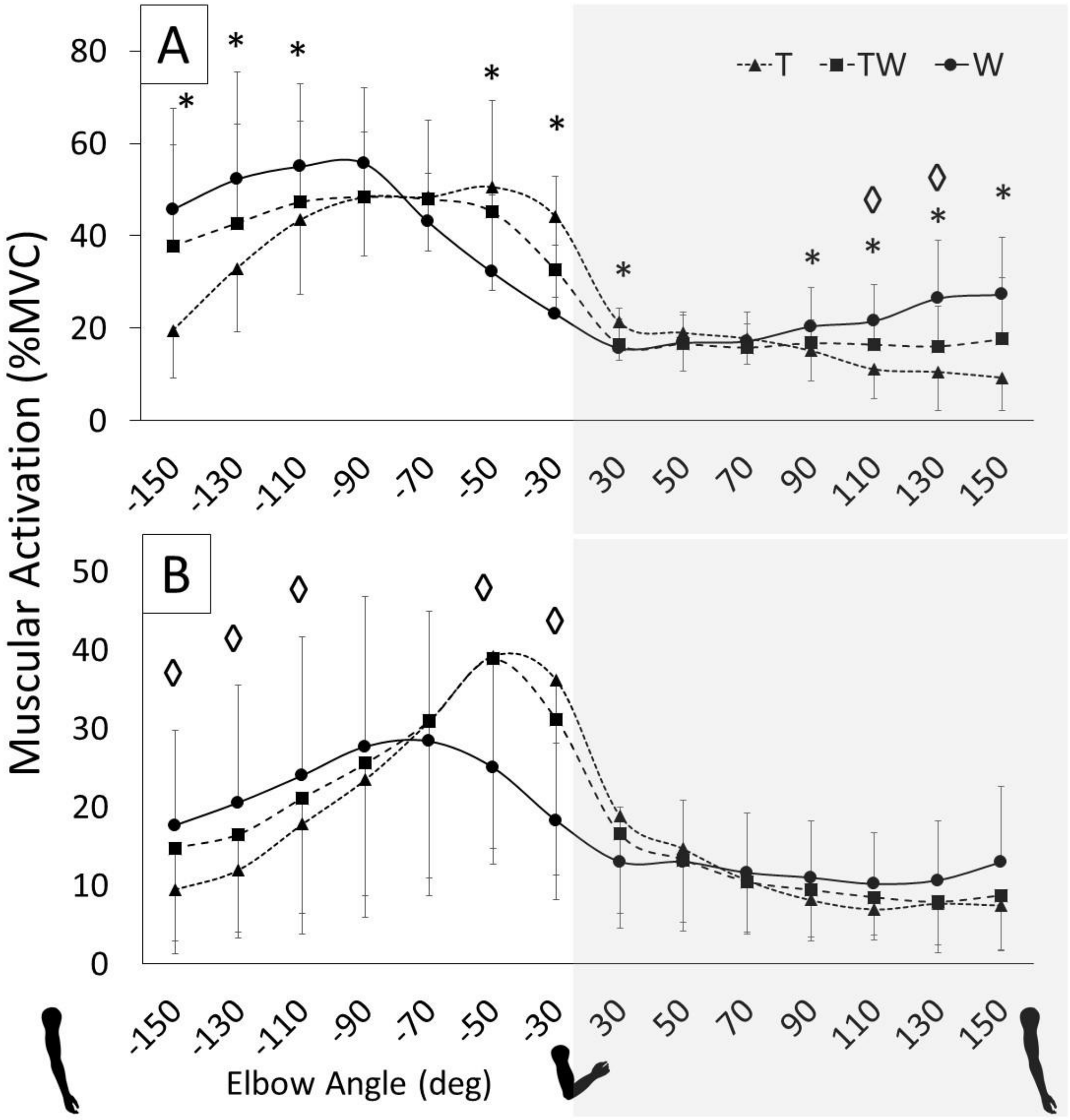
Figure 2. Mean ± SD peak muscular activation when exercising with three different resistance methods: tubes (T), tubes and weights combined (TW), weights only (W).* W significantly lower (p=.004) than T and TW.

Figure 3. Mean ± SD muscular activation of the biceps brachii (A) and the triceps brachii (B) muscles per every 20° of ROM, during a bicep curl performed with three different resistance methods: tubes (T), tubes and weights combined (TW), weights only (W). * Significant difference (p<.05) between T and W; ◊ Significant difference (p<.05) between W and TW.

Figure 4. Mean ± SD muscular activation of the rectus femoris (A), vastus medialis (B) and vastus lateralis (C) muscles per every 20° of ROM, during a leg extension performed with three different resistance methods: tubes (T), tubes and weights combined (TW), weights only (W). ♦ W is significantly (p<.001) different than all other conditions; ◊ W is significantly different (p<.001) than T.


□ T ■ TW ■ W
Ratio of Total Activation
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
*
Biceps Brachii
Triceps Brachii
Rectus Femoris
Vastus Medialis
Vastus Lateralis
Bicep curl
Leg Extension


□ T ■ TW ■ W
Peak Activation (%MVC)
120
100
80
60
40
20
0
*
Biceps Brachii
Triceps Brachii
Rectus Femoris
Vastus Medialis
Vastus Lateralis
Bicep curl
Leg Extension


A
B
T
TW
W
Muscular Activation (%MVC)
Elbow Angle (deg)
0
20
40
60
80
0
10
20
30
40
50
-150
-130
-110
-90
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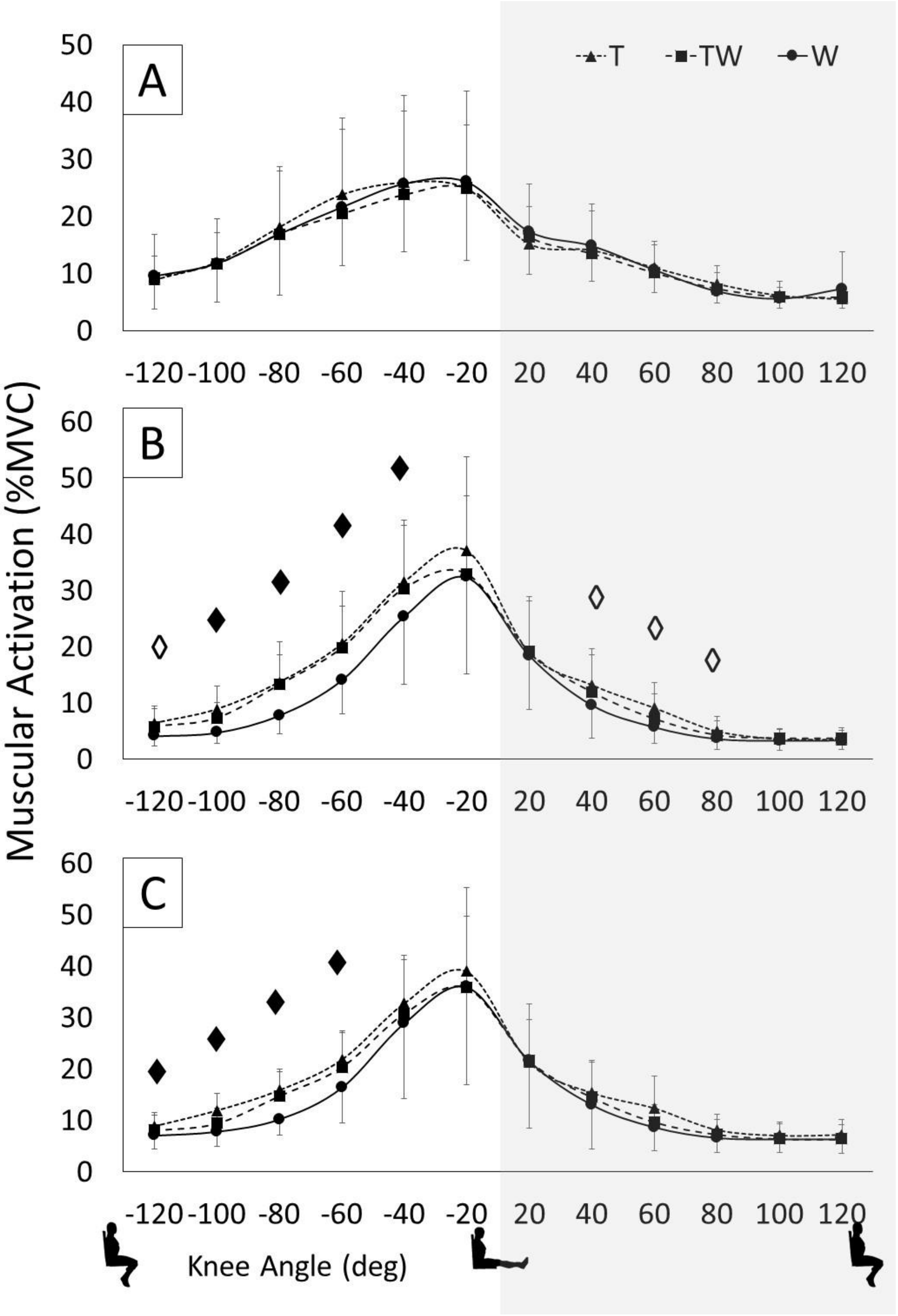
A
B
C
T
TW
W
Muscular Activation (%MVC)
0
10
20
30
40
50
60
-120
-100
-80
-60
-40
-20
20
40
60
80
100
120
Knee Angle (deg)