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Effects of Lift Velocity on Muscle Activation During Leg Extension

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Abstract: It is not known if manipulating velocity within a prescribed resistance training mode will improve muscle activation. Muscle activations of the Rectus Femoris (RF), Vastus Lateralis (VL), Vastus Medialis (VM) and Bicep Femoris (BF) were examined during a leg extension exercise at 3 different velocities on 15 subjects (10men, 5 female, Age = 21.5 ± 1.8 yrs, Height = 171.2 ± 12.5 cm, Mass = 75.5 ± 16.3 kg). Trials of 1 set of 10 repetitions at 60% of 1RM, were performed at 15, 30 and 60º/s. Bipolar surface electrodes were placed over the BF, RF, VL, and VM. Micro-switches were utilized to identify the concentric (CON) and eccentric (ECC) phases of the lift. Data were sampled at 1024 Hz, filtered, rectified and the mean, integrated EMG calculated. One 2 x 4 x 3 (action x muscle x velocity) ANOVA with bonferonni adjustment was run and significance was followed by Tukey HSD post hoc analysis. Results indicated significantly greater activation of the VL, RF and VM for ECC extension at 60º/s compared to 15º/s. While 60º/s was also greater than 30º/s for the VL and VM during ECC. While comparing muscle action, CON VL, VM and RF were greater than ECC at 30º/sec, meanwhile VM CON was also greater at 15º/sec. No differences in muscle activation at any velocity or muscle action for BF were identified. We conclude that muscle recruitment while training with a 60% 1RM load is maximized at a velocity of 60º/s during ECC activity and 15 or 30º/sec during CON.

Keywords: EMG, lift speed, muscle recruitment, training velocity.

INTRODUCTION

In the health and fitness setting, the goal of strength training programs is often to establish appropriate resistance training loads in an attempt to maximize outcomes for strength and performance. Traditionally, these programs have focused on theories based on the number of repetitions, numbers of sets and the amount of weight to be lifted in order to maximize muscular output [1-7]. Proper instructions in regards to lifting technique, in combination with adequate volume (sets, reps) often are given only during initial consultations.

Another aspect of the exercise sometimes identified, is the velocity of the lift. It is well documented that the velocity of movement of a load is inversely related to the load, so the heaviest loads elicit the slowest lift velocity [1]. Conversely, the lighter loads can be moved at much higher velocities. For novice to intermediate weight lifters it is recommended that training intensity be 60 – 70% of 1 RM with 8 – 12 repetitions [1, 8, 9]. At these loads a range of velocities exist where the individual can complete the repetitions while maintaining proper form. However it is not clear if muscle activation varies within these velocities. Traditional instructions have involved a slow concentric phase followed by a brief pause then concluded with an even slower eccentric phase. Anecdotally, it has been thought that this slow training maximizes strength gain, and some authors have advocated for super slow training [10, 11]. Within these load ranges, some variation in speed has been examined. At one end of the speed spectrum, slow training has not shown itself to be as effective as faster movement for strength development. Hatfield *et al.* [12] compared slower velocity training (10s concentric, 5s eccentric) at 60 and 80% of 1 RM to a self-selected lift cadence. They found that subjects who completed significantly lower training volume during slower training, indicated a higher effort rating, and had a reduced power output compared to the faster self-selected lift speed.

Much of the research examining slower velocity resistance training has suggested poor outcomes in respect to strength gains, muscle recruitment, metabolic cost and lifting volume [1]. Many investigations examining lifting velocities have considered those that are either much slower than conventional practices [13] or much faster [2, 14, 15]. In addition, most studies have used isokinetic or hydraulic exercise modes, rather than isotonic [16]. It is not known to what degree minor variations in lift velocity affect the amount of muscle activation experienced during a lift. Authors [14, 17-20] have identified that more hypertrophy and / or strength gains have come from training protocols involving higher ECC velocities. However, it should be noted that the velocities examined were higher than the present investigation. Concentric resistance training recruits more muscle at low velocities, with force production dropping as the velocity increases. Conversely, ECC contractions are greatest at higher velocities. These changes are seen across a large range of contraction velocities. It is not known whether there are changes in muscle activation patterns across a more narrow range of speeds, and one that utilizes a load conducive to strength gain. If subtle variations in velocity do not result in activation changes, conventional speed model exercise prescriptions would be adequate.

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However, if slight variations (15, 30 and 60º/sec) in velocity do result in activation differences, exercise prescriptions should reflect those benefits.

The purpose of this investigation was to examine muscle activation during a leg extension exercise completed at three lift velocities. The highest velocity that could be completed while maintaining technique was 60º/sec, while two slower (15, 30º/sec) velocities were chosen to represent a practical range of lifting velocities that may be encountered in a typical fitness setting.

MATERIALS AND METHODOLOGY

Past research has indicated that strength development occurs when using loads ranging from 60% - 95% 1RM [1]. The present investigation examined the use of a load suitable for strength development while varying the velocity of the lift and assessing muscle activation. Pilot testing assisted the authors with determining the lifting velocities that subjects would be able to complete with proper form, while the slowest velocity was chosen to create a condition similar to slower training [21].

Fifteen subjects (10 men, 5 female, Age = 21.5 ± 1.8 y, Height = 171.2 ± 12.5 cm, Mass = 75.5 ± 16.3 kg) were recruited for this investigation. Subjects were familiar with strength training, and had been actively lifting within the past six months. Subjects provided signed consent in accordance with the Institutional Review Board, who approved the study. All subjects completed an initial orientation day, where they were provided a familiarization with the activity, machine and completed an estimation of one repetition maximum (1RM). Subjects were positioned according to manufacturer recommendations for the variable resistance, leg extension exercise (Badger Magnum Selecterized Equipment) and instructed as to the proper form. An estimated 1RM for leg extension was assessed using the equation of Bryzycki [22]. Cadence was practiced at 15º/sec (6 s concentric, 6s eccentric), 30 º/sec (3s concentric, 3s eccentric) and 60º/sec (1.5s concentric, 1.5s eccentric). A metronome and a micro-switch at each end of the range of motion assisted the subjects' performance at the proper cadence and within a standardized range of motion.

Subjects reported to the Human Performance laboratory on a second occasion for trial testing. The dominant leg, as determined by handedness of the subject, was used for electrode placement. The skin was prepped for electrode placement by shaving the designated areas to remove hair and abraded using a coarse pad and rubbed clean with rubbing alcohol and a towel. These procedures were followed until the skin impedance was found to be less than 10,000 ohms using a standard ohmmeter [23].

The Biopac® Tel-100 EMG system (Goleta, CA) was used to measure muscle electrical activity and record the data from each subject. The EMG data were analyzed using Acqknowledge™ software. Bipolar adhesive surface electrodes (Ag-AgCl, 2cm inter electrode distance) were used over the muscle bellies of the involved muscles. The electrodes were placed parallel to the direction of the muscle fibers on the vastus medialis oblique (VM) vastus lateralis (VL), biceps femoris (BF) and rectus femoris (RF). The fibers of the VM run at approximately a 55-degree angle medial to the quadriceps tendon, and the electrode was placed 20% of the distance from the medial joint line of the knee to the anterior superior iliac spine. The fibers of the VL are at 12 to 15-degrees lateral to the quadriceps tendon; the electrode was placed at the midpoint between the head of the greater trochanter and the lateral femoral epicondyle. Ground electrodes were placed on the patella and 6 to 8 cm from the inferior pole of the patella along the bony shaft of the anterior tibia. For the BF, electrodes were placed on the posterior thigh along a line of reference between the ischial tuberosity and the lateral popliteal surface directly over the gaster of the muscle. A ground electrode was placed on the head of the fibula. For the RF, electrodes were placed on the anterior aspect of the thigh midway between the anterior superior iliac spine and the patella. A ground electrode was placed on the tibial tuberosity.

Subjects completed one set of 10 repetitions at 60% of 1RM, performed at 15, 30 and 60º/sec, representative of the range of lifting velocities. Trial order was counterbalanced, and subjects were given 5 minutes between each set to rest. Subjects were asked to match the cadence set by the metronome for each trial. When a subject was unable to match the cadence, the trial was suspended, the subject rested, and the trial repeated. Two separate channels on the Biopac were configured into the digital box to accept input from switches denoting the starting and ending range (90-180 degrees) of motion, and were activated by the arm of the leg extension equipment.

Data were sampled at 1024 Hz (gain = 2,000) and stored. Post-test filtering to smooth motion artifact was conducted using Acqknowledge Software (Microsoft Corp.). A high-pass filter with a cutoff frequency of 30 Hz using 255 coefficients (Blackman -67) was used. Data were then rectified and integrated. The final IEMG values for each concentric and eccentric phase of the exercise were identified using the micro-switch data (Fig. **1**). Samples were averaged across 5 repetitions (repetitions 3-7) in order to avoid initial errors in velocity as well as fatigue effects [23].

One 2 x 4 x 3 (action x muscle x velocity) ANOVA was used; significance was followed by Tukey HSD post hoc analysis. Velocity effects on muscle activation were of interest, therefore gender effects were not considered in this analysis. Data were analyzed using the SPSS software14.0. (Chicago, IL). Significance was set at $p<.05$ and Bonferroni adjustments were made. Stability of IEMG data were analyzed by calculation of intra-class correlation (ICC) coefficients. In all cases, ICC values exceeded .90 (range .904 to .994).

RESULTS

Significantly greater activation was identified in the VL ($p=.001$), RF (.003) and VM (.000) for ECC extension at 60º/sec compared to 15º/sec (Figs. **3-5**). While 60º/sec was also greater than 30º/sec for the VL (.023) and VM (.019) during ECC (Figs. **3**, **5**). While comparing muscle action, CON VL (.007), VM (.004) and RF (.025) were greater than their respective ECC at 30º/sec, meanwhile VM CON (.001) was also greater at 15º/sec (Figs. **3-5**). No differences in muscle activation at any velocity or muscle action for BF were identified (Fig. **2**).

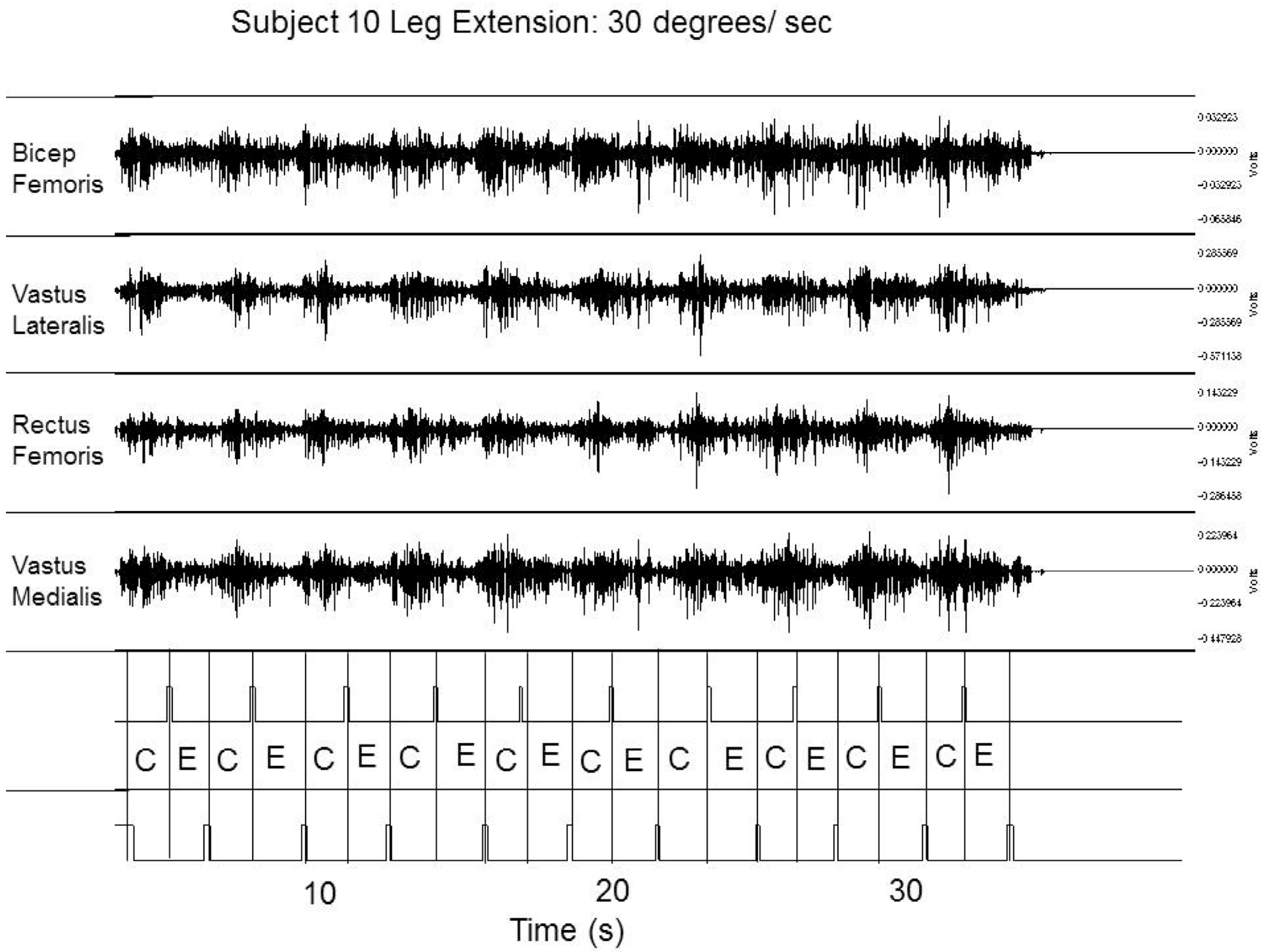

Fig. (1). Example of EMG sampling during leg extension trial: 30 degrees per second. C denotes Concentric and E denotes Eccentric. Contractions are divided by electronic position markers.

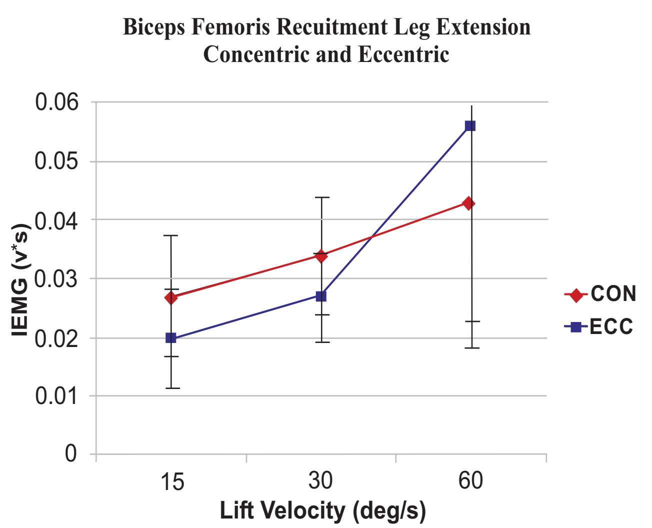

Fig. (2). Biceps Femoris activation during leg extension across lift velocities. No significant differences identified.

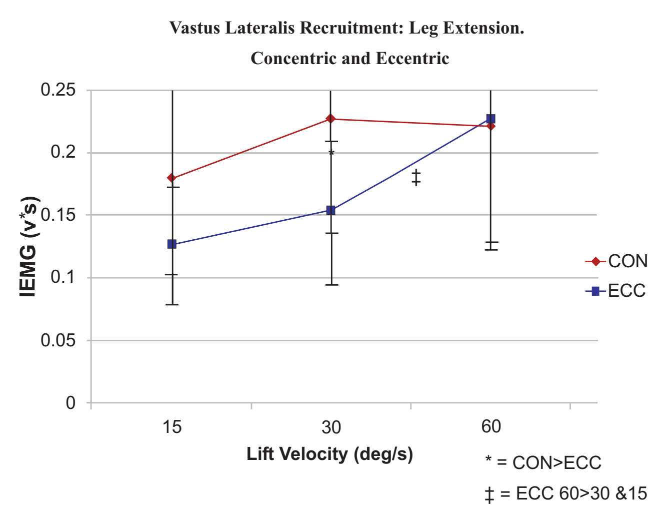

Fig. (3). Vastus Lateralis activation during leg extension across lift velocities. ECC 60 °/sec significantly greater than both 30 and 15 °/sec. No differences during CON at any velocity. CON is greater than ECC at 30 °/sec.

DISCUSSION

The major finding of this study is that ECC training at 60 º/sec was responsible for greater peak muscle activation when compared to slower lifting velocities (15 and 30º/sec). The present investigation is consistent with previous findings of greater muscle hypertrophy, strength and activation in response to faster ECC training [18-20]. An interesting aspect of the present project is that despite an only 45º/sec difference from the slowest (15º/sec) to the fastest velocity (60º/sec) that significant differences were identified in muscle activation. This is an important finding and has direct implications in the exercise prescription of recreational lifters. Farthing and Chilibeck [20] implemented an 8 week investigation looking at the effect of eccentric and concentric training at slow (30º/sec) and fast velocities (180º/sec). Eccentric training at the higher velocity showed a 13% increase in hypertrophy when compared to eccentric training at slower velocities (7.8%).

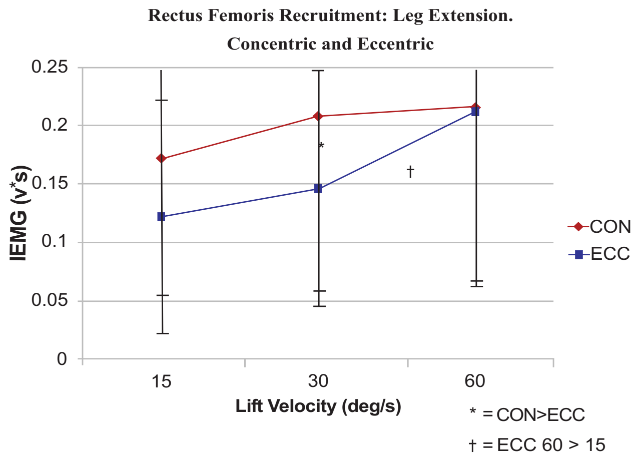

Fig. (4). Rectus Femoris activation during leg extension across lift velocities. ECC 60 º/sec significantly greater than 15 º/sec. CON is greater than ECC at 30 º/sec.

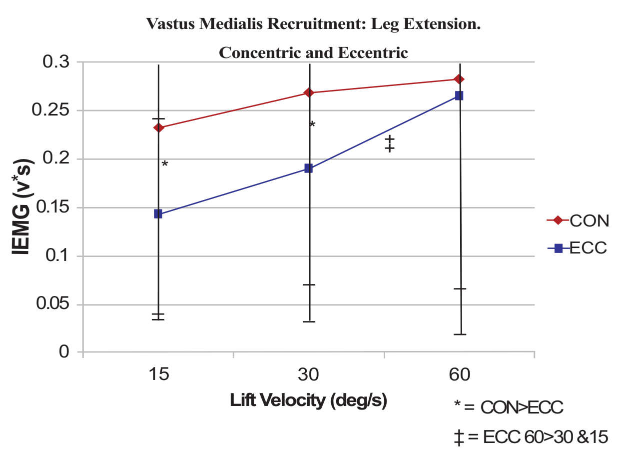

Fig. (5). Vastus Medialis activation during leg extension across lift velocities. ECC 60 º/sec significantly greater than both 30 and 15 º/sec. CON is greater than ECC at 30 and 15 º/sec.

Some subscribe to the theory of super slow resistance training (10 sec CON, 4 sec ECC). The theory is based on the thought that the tension within a muscle is related to the number of motor units firing and to the frequency with which impulses are conveyed to the motor neurons [24]. Using a slower speed is thought to require the activation of more muscle fibers and an increase in the frequency of firing in order to maintain a force necessary to lift a given workload [25]. Westcott [11] investigated on two occasions the effects of a slow training (10 sec CON, 4 sec ECC) regimen in contrast to a regular training velocity (2 sec CON, 4 sec ECC) program [11]. A 12.0 and 10.9 kg increase in the slow velocity group were noted compared to an 8.0 and 7.1 kg increase in the regular training velocity group. These findings are disputed by that of Paddon – Jones *et al*. [26,27] and Farthing and Chilibeck *et al*. [20] who showed that eccentric training at higher velocities (180º/sec) produced greater increases in strength than training at slower velocities (30º/sec). Additionally, Neils and Udermann [14] examined the effects of an 8-week resistance training program of either a traditional resistance training program (2 sec CON, 4 sec ECC) or a super slow training program (10 sec CON, 5 sec ECC). They found greater increases in muscular power in the traditional program when examining the countermovement jump. They continued by stating that a super slow program is not an optimal method of training and the specificity of a short concentric contraction phase tends to favor explosive activities, which they evidenced by the 8.4% increase experienced in the traditional resistance training protocol. It should be noted that the investigation by Neils and Udermann [14] involved an 8 week training protocol and used resistance as their outcome measure, while the current investigation examined muscle activation through EMG.

It is difficult to identify a specific mechanism that is responsible for the disparities that exist in the findings of others investigating the relationship of velocity on muscle function. Investigations have been shown to vary by measurements (hypertrophy, strength, and activation), training regimen (frequency, duration) and by the specifics of velocity during each repetition. For instance some authors controlled the CON and ECC phases independently [11, 14] while others [20, 27] kept the velocity consistent throughout the task. Since force production varies by training velocity and contraction type, it is interesting that few studies exist that examine the specific mechanisms of such determinants [18, 20, 28, 29]. As a function of the force – velocity relationship typically with concentric contractions force output decreases significantly with increasing contraction velocity [30-32]. Conversely, with eccentric contractions, force output increases with increasing contraction velocity [32, 33]. Our findings support such a determinant. We noted at slower velocities (15 and 30º/sec) that CON activation was significantly greater than ECC activation within velocity. This provides further support that as velocity increases muscle activation during CON phase activation is attenuated.

The present investigation manipulated velocity by defining the CON and ECC phases as being the same in length. In all cases the CON phase equaled the timing of the ECC phase. Based on this model we were able to show that a significant increase in activation occurred at faster velocities eccentrically. Additionally, when comparing within each velocity we identified more activation at 15 and 30º/sec within the CON phase of the repetition. Across all findings it is clear that most activation occurs during faster ECC contractions and the CON activation patterns begin to taper off as velocity increases. Differences in activation are further separated as velocity increases [20]. Some authors have speculated that changes in muscle fiber type or increased ability to selectively recruit fast-twitch motor units may play a role in the higher activation noted at increased velocities [26]. Others have also stated that the same amount of work at a lower metabolic cost and perceived rate of exertion may be a result of ECC training [34-36]. Additionally, when it pertains to concentric contractions at slower velocities it has been reported that within the muscle fiber, the slower the rate at which the actin and myosin filaments slide past each other, the greater the number of links or cross-bridges that can be formed between them [25]. The more the cross-bridges there exist per unit of time, the more tension is created and therefore at slow contraction velocities a higher number of cross-bridges can be formed leading to higher tension development.

Current strength and conditioning guidelines recommend resistance training at or above 60% 1RM to achieve increases in strength [1,8]. Meanwhile, it is important to identify the velocity by which participants may experience maximum muscular activation while maintaining a proper technique. Others have purported that higher velocity training increases muscle activation [5, 21]. However, these investigations included exercise techniques (Olympic lifts, ballistic training) that differ from isotonic training. Our findings indicate that muscle activation can be enhanced at modest loads by lifting at a slightly higher velocity during the ECC phase of the movement. The findings of greater activation ECC during faster movements and the growing difference between activation during slow and fast contraction velocities allows the current authors to postulate that increases in muscle activation will continue as functional performance occurs. Programs that include a functional velocity into resistance training may see additional benefits not noted in the traditional resistance training programs.

The present investigation found during ECC muscle activity that slightly increased velocity resistance training programs within a functional range of motion results in significantly greater muscle activation than at slower speeds. Strength and velocity are both important components of functional performance [1], and our data suggest that one can train at a load sufficient for strength gain, while also improving muscle activation, simply by increasing the speed of movement. It should be noted that this investigation did not examine the effect of slower speed training with higher resistance rather only looked at the effects on recruitment from varied velocities with a constant resistance.

CONCLUSION

While athletic populations typically train specifically for improving aspects of muscular strength, power and agility, recreational populations often do not employ extensive training regimens. Instead, they may only use a traditional resistance training session, exercising major muscle groups two or three days per week. Our data suggest that simply training at a slightly higher velocity of ECC with proper technique will significantly increase muscle activation. Training instructions could be modified to suggest that the client concentrically accelerates in a controlled manner while still maintaining a smooth motion, and eccentrically lowers at a faster velocity which still can be controlled.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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