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Original Research Article

Attenuated Kinetic and Kinematic Properties During Very Slow Tempo Versus Maximal Velocity Resistance Exercise

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Abstract

Purposely slow velocity resistance exercise (i.e., 10 sec concentric and 10 sec eccentric), sometimes called slow tempo, is a popular training method, but limits the loads that can be lifted (e.g., <50% 1RM). This study compared the biomechanical properties of slow tempo (SLOW) and maximal velocity (MAX) resistance exercise. Healthy resistance-trained men (n=5) performed two testing sessions (barbell squat and bench press) in random-order; a SLOW session (1 set x 10 repetitions at 28% 1RM, 10 sec concentric and 10 sec eccentric), and a MAX session (3 x 10 at 70% 1RM, volitionally controlled eccentric and maximal concentric velocities). A force plate and linear position transducer were used to collect kinetic and kinematic data for every repetition of both protocols. Statistical significance was set at $\alpha=0.05$. For both exercises, both concentric and eccentric mean force (N) and power (W) for each repetition were greater for MAX. When the entire training session (barbell squat and bench press) was examined, SLOW exhibited greater time under tension, while MAX produced greater work (J) and impulse (N·s). Contrary to suggestions in both the lay and scientific literature, SLOW resistance exercise produced less force, power, and work than MAX resistance exercise.

Key words: force, power, impulse, weight training, biomechanics, coaching

INTRODUCTION

Resistance exercise has been used for many years to enhance health and sport performance. There are a number of ways to vary resistance exercise, including altering exercise selection, order of performing exercises, load being lifted, and velocity of the lift (Fleck & Kramer, 2014). Of these, altering the velocity of a submaximal resistance exercise by performing the movements at a very fast or a very slow velocity may lead to differing effects. Controlled slow velocity, also known as slow tempo (SLOW) resistance exercise, is a form of resistance exercise in which the speed of the movement is drastically reduced or controlled to a certain tempo. This is distinctly different from commonly used types of resistance exercise which often encourages movement to be as fast as possible (Greer, 2005). Over the years, SLOW resistance exercise has gained some popularity because of the simplicity of the program, the short duration it purportedly takes to perform each training session, claimed safety considerations, and supposed physiological training benefits (Brzycki, 1995; Carpinelli *et al*., 2004; Hutchins, 1992; Westcott, 1999; Winnett & Carpinelli, 2001). While several recent reviews have addressed this topic, none of them examined the biomechanical characteristics of exercise sessions such as typically used in SLOW resistance training (Davies *et al*., 2017; Greer, 2005; Hackett *et al*., 2018; Schoenfeld *et al*., 2015; Wilk *et al*., 2020).

Those who advocate using SLOW training with submaximal loads for healthy individuals and for sports performance promote this type of resistance exercise as a way to safely and effectively increase muscle size and increase resting metabolism, thus promoting weight loss (Hunter *et al*., 2003; Westcott, 1999; Winnett & Carpinelli, 2001). In some cases, this type of resistance exercise may be extremely slow (e.g., as slow as a 10 sec eccentric phase and a 10 sec concentric phase). Proponents for resistance exercise at this slow of a lifting tempo claim that only 1-2 training sessions per week need to be performed depending on the size of the muscles (Brzycki, 1995; Hunter *et al*., 2003). Numerous proposed benefits for SLOW resistance exercise can be found in the lay literature, including potential improvements in strength, bone density, cardiovascular efficiency, flexibility, resistance to injury, improved blood pressure, as well as decreased body fat (Brzycki, 1995; Westcott *et al.*, 2001). In one of the recently conducted studies, Wilk *et al*. (2018) found that SLOW resistance training had the highest time under tension and lowest training volume when compared to medium and regular exercise tempos. Additional claims include physiological changes such as increased muscular endurance for daily functions and enhanced sport performance (Brzycki, 1995; Hunter *et al*., 2003; Westcott, 1999). Regardless of the exact tempo, few scientific data are available concerning the biomechanical properties of this type of training (Keeler *et al*., 2001; Schilling *et al*., 2008).

Several biomechanical claims for SLOW resistance exercise have been challenged (Schilling *et al*., 2008). For the purposes of this paper, maximal velocity (MAX) resistance exercise will be defined as training where the resistance is moved either as rapidly as possible or attempts are made to move the resistance quickly (i.e., typically ≤ 1 sec concentric and ≤ 1 sec eccentric phases). Proponents of SLOW resistance exercise claim the force one produces is increased during SLOW training because momentum is decreased compared to MAX exercises (Brzycki, 1995; Westcott, 1999). The argument is that during a MAX resistance exercise, momentum is increased at the beginning of the repetition, supposedly allowing the weight to contribute to the movement and reducing the effort throughout the full exercise range of motion (Brzycki, 1995; Hatfield *et al*., 2006; Hunter *et al*., 2003; Westcott, 1999). However, it must be noted that Newtonian physics defines force as a product of mass and acceleration, and momentum as a product of mass and velocity, which means increasing force requires increasing momentum (McGinnis, 2005, Schilling *et al*., 2008). Another supposed benefit of SLOW resistance exercise is an increase in power due to the purported increase in force (Westcott, 1999; Westcott *et al.*, 2001). In actuality, a reduction in velocity would require a considerable increase in force magnitudes in order to increase the resultant power (McGinnis, 2005; Schilling *et al*., 2008). During SLOW resistance exercise, each repetition, and each set require a longer duration to complete. The increased duration of time may increase the perceived difficulty of the exercise, sometimes known as effort. Some refer to this as "the intensity stimulus" which is related to the degree of effort required (Schilling *et al*., 2004). It should be noted, however, that the relative load for resistance exercise is often used to describe an exercise's intensity (Fry, 1999; Fry, 2004). For SLOW training, the load must be reduced as the velocity is purposely decreased. Therefore, SLOW training is not high intensity training by the generally accepted definitions (Fry, 2004). It has also been claimed that SLOW resistance exercise increases the amount of work being performed (Brzycki, 1995). During SLOW resistance exercise, the amount of time is increased, but the amount of mechanical work is likely to decrease since mechanical work is a product of force produced and the distance moved (Knuttgen & Kreamer, 1987; McGinnis *et al*., 2005). During both SLOW and MAX resistance exercise, as long as the exercises are the same, the distance moved should be similar, if not equal. However, the forces likely differ between the two protocols due to the lower acceleration during SLOW resistance exercise (Schilling *et al*., 2008).

Previous research has demonstrated that, when SLOW resistance exercise was compared to a MAX lifting protocol, the VO2, heart rate response, and energy expenditure was comparable or higher for the MAX protocol (Hunter *et al*., 2003; Kim *et al*., 2011; Mazzetti *et al*., 2011; Wickwire *et al*., 2009). In addition, post exercise lactate concentrations were almost two times greater for MAX resistance exercise compared to SLOW resistance exercise (Hunter *et al*., 2003). One study on the endocrine responses to two different SLOW resistance exercise protocols reported few differences in the measured hormones (Headley *et al*., 2011). However, it should be noted that both velocities used were SLOW when compared to expected velocities for the loads used (González-Badillo & Sánchez-Medina, 2010; Mann, 2016). Since MAX resistance exercise produces greater energy expenditure than SLOW resistance exercise, it may be a more beneficial protocol for body mass control (Hunter *et al*., 2003). In a different study, SLOW resistance exercise with untrained women has been shown to improve muscular strength and muscular endurance, but not to a greater extent than MAX strength training (Rana *et al*., 2008). It has also been reported that SLOW resistance training resulted in greater strength increases when compared to MAX training, however, different methods of strength testing were used for each group, thus drawing into question the results (Westcott *et al.*, 2001). Although many of the claimed characteristics of purposely SLOW resistance exercise seem to disagree with basic biomechanical principles, there are few studies that have directly examined the kinetic characteristics of this type of training (Hatfield *et al*., 2006; Headley *et al*., 2011; Schilling *et al*., 2008). Based on basic Newtonian physics, it is hypothesized that when compared to a commonly used resistance exercise training protocol, SLOW resistance exercise will produce lower forces and powers, but the entire session will produce identical mechanical work and impulse. Thus, the purpose of the present study was to analyze the kinetic and kinematic properties of SLOW and MAX resistance exercise training sessions.

METHODS

Subjects

Five healthy, currently resistance-trained men, who were familiar with the high-bar parallel barbell squat and barbell bench press, served as subjects (X±SD; age=25.8±3.3 yrs, height=1.76±0.07 m, body mass (BM)=92.7±18.7 kg). All subjects were tested for 1 repetition maximum (1RM) for both the bench press (1RM=122.0±29.1 kg; 1RM/BM=1.38±0.23 kg·kg^{-1}) and the squat (1RM=165.0±46.0 kg; 1RM/BM= 1.79±0.42 kg·kg^{-1}) exercises (Kreamer *et al*., 2006). All subjects provided informed consent as approved by the University Human Subjects in Research Committee.

Procedures

The present study used a repeated-measures randomized cross-over design to compare the biomechanical characteristics of a SLOW resistance exercise protocol with a MAX resistance exercise protocol. Each subject performed two testing sessions in random order; a MAX resistance exercise protocol and a SLOW resistance exercise protocol. Data collection occurred over a three-week period, with testing occurring during the same time of day for each session (16:30-19:00 hrs) to avoid possible diurnal changes in strength levels (Kreamer & Ratamess, 2005). Subjects were asked to refrain from eating three hours prior to testing and to avoid a strenuous workout 48 hrs prior to testing. To increase external validity, both resistance exercise training protocols were selected to replicate commonly performed protocols for both types of resistance exercise, rather than to equate training session volume.

For each exercise protocol, barbell position was monitored using a ceiling-mounted Uni-Measure linear position transducer (Corvallis, OR, USA) with a wire cable connected to the barbell. Ground reaction forces were determined with a uni-axial force plate (Rough Deck, 0.91 m x 2.44 m, Rice Lake Weighing Systems, Rice Lake, WI, USA). The forces included each subject’s body mass. When performing bench press exercises, the bench was placed completely on the force plate, and the subjects constantly maintained five points of contact. The force due to the bench was subtracted from the value of the ground reaction force. All data were sampled at 1000 Hz using a 16-bit analog-to-digital converter and a Biopac data acquisition system (MP150, Biopac Systems, Inc., Santa Barbara, CA, USA). A Chronomix digital electronic timer (NewChron Associates, Walnut Creek, CA, USA) was used as an audio and visual cue to maintain the prescribed lifting tempo for the purposely SLOW resistance exercise, and to monitor the inter-set and inter-exercise rest intervals for both sessions.

The SLOW training used 28% of 1RM loads for the squat, followed by the bench press exercise, as suggested from previous slow tempo resistance exercise studies and pilot work in our laboratory that indicated this intensity was the maximum that could be lifted for 10 repetitions (Hunter *et al*., 2003; Keeler *et al*., 2001; Wickwire *et al*., 2009). The SLOW protocol also used 1 set of 10 repetitions at a 10 sec eccentric phase, 10 sec concentric phase tempo with no rest between repetitions. Rest intervals were 2 min between exercises. This protocol was based on prior studies (Hatfield *et al*., 2006; Hunter *et al*., 2003; Keeler *et al*., 2001), as well as recommendations from proponents of SLOW training (Brzycki, 1995; Hutchins, 1992; Westcott, 1999). The MAX resistance exercise protocol consisted of 3 sets of 10 reps at 70% 1RM loads with 1 min rest between sets and 2 min rest between the squat and bench press exercises, as is commonly recommended for resistance training for fitness (Beachle & Earle, 2008; Fleck & Kramer, 2014). For the MAX resistance exercise session, subjects were instructed to perform each repetition at a volitionally controlled eccentric velocity, and maximum concentric velocity.

Dependent Variables

Position (m), time (s), and force (N) variables were directly measured for both the concentric and eccentric phases for all sets and repetitions for both exercise protocols. The first derivative of position was used to calculate barbell velocity (m·s^{-1}), whereas distance moved (m) was determined from position. Additional calculations were used to determine repetition power (W; force x velocity), total training session mechanical work (J; force x distance), and impulse (N·s; average force across repetition x time). For each subject, values for all repetitions were averaged. Finally, the time under tension (sec) for the entire training session was the sum of times for all concentric and eccentric phases of all repetitions performed.

STATISTICAL ANALYSES

Dependent t-tests determined differences between SLOW and MAX sessions for each of the dependent variables. Hedge’s g was used to measure the effect sizes between the means. Significance was set a priori (α=0.05). All data are reported as means, standard deviations, and 95% confidence intervals. Statistical software SPSS 24.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Based on anticipated large differences for force and power from previous related research (Hatfield *et al*., 2006), our sample size was adequate and statistical power was 0.95.

RESULTS

Numerous significant differences were observed between SLOW and MAX conditions for both the squat (Table 1) and the bench press exercises (Table 2). The SLOW protocol took significantly more time to complete the exercises compared to MAX resistance exercise for both concentric and eccentric phases (Tables 1 and 2). The eccentric and concentric displacement measures were not significantly different between the two protocols which demonstrate the range of motion (ROM) for the exercises remained the same. The concentric and eccentric mean forces and powers were significantly greater for the MAX session for both the squat (Table 1) and bench press (Table 2). When comparing the entire session for both protocols (squat and bench press analyzed together), the SLOW session had significantly greater time under tension (TUT) compared to the MAX session (Figure 1). Mechanical work was significantly less in the SLOW session in contrast with the MAX session (Figure 2). Impulse was also significantly lower during SLOW compared to MAX (Figure 3).

Table-1: Comparison of squat kinetic and kinematic variables between purposely slow velocity (SLOW) and maximal velocity (MAX) resistance exercise (X±SD [95% CI]).

Squat Variables	SLOW	MAX	p-value	Effect Size
Eccentric Mean Velocity ($m\cdot s^{-1}$)	-0.028±0.085 [-0.047–0.103]	-0.715±0.069 [-0.775– -0.655]	<0.001*	8.87
Concentric Mean Velocity ($m\cdot s^{-1}$)	0.091±0.064 [0.035–0.147]	0.589±0.098 [0.503–0.675]	0.001*	6.13
Eccentric Displacement (m)	0.663±0.069 [0.603–0.723]	0.680±0.030 [0.654–0.706]	0.453	0.32
Concentric Displacement (m)	0.662±0.068 [0.602–0.722]	0.702±0.032 [0.674–0.730]	0.085	0.75
Eccentric Mean Force (N)	1406.8±405.2 [1051.6–1761.9]	1942.7±347.3 [1638.3–2247.1]	0.010*	1.42
Concentric Mean Force (N)	1409.5±450.2 [1014.9–1804.1]	2030.8±378.4 [1699.1–2362.5]	0.008*	1.49
Eccentric Mean Power (W)	-93.5±23.8 [-114.4– -72.6]	-1358.9±285.3 [-1608.9– -1008.8]	<0.001*	6.25
Concentric Mean Power (W)	91.9±21.5 [73.1–110.7]	1172.8±267.7 [938.2–1407.4]	0.001*	5.69
Eccentric Time (sec)	9.81±0.36 [9.49–10.13]	0.96±0.06 [0.907–1.013]	<0.001*	34.29
Concentric Time (sec)	9.95±0.67 [9.36–10.54]	1.23±0.19 [1.063–1.397]	<0.001*	17.71
*p<0.05				

Table-2: Comparison of bench press kinetic and kinematic variables between purposely slow velocity (SLOW) and maximal velocity (MAX) resistance exercise (X±SD [95% CI])

Squat Variables	SLOW	MAX	p-value	Effect Size
Eccentric Mean Velocity ($m\cdot s^{-1}$)	-0.042±0.010 [0.033–0.051]	-0.533±0.086 [-0.608– -0.458]	<0.001*	8.02
Concentric Mean Velocity ($m\cdot s^{-1}$)	0.040±0.006 [0.035–0.045]	0.389±0.075 [0.323–0.455]	0.001*	6.56
Eccentric Displacement (m)	0.400±0.051 [0.355–0.445]	0.393±0.025 [0.371–0.415]	0.789	0.17
Concentric Displacement (m)	0.400±0.050 [0.356–0.444]	0.400±0.036 [0.368–0.432]	0.985	0.01
Eccentric Mean Force (N)	445.5±194.7 [274.8–616.2]	956.6±280.3 [710.9–1202.3]	0.046*	2.12
Concentric Mean Force (N)	447.5±195.1 [276.5–618.5]	1031.2±309.1 [760.3–1302.1]	0.036*	2.26
Eccentric Mean Power (W)	-19.1±10.3 [-28.1– -10.1]	-562.0±198.3 [-735.8– -388.2]	0.005*	3.87
Concentric Mean Power (W)	18.7±10.8 [9.2–28.2]	396.8±152.3 [263.3–530.3]	0.006*	3.50
Eccentric Time (sec)	9.59±0.44 [9.21–9.98]	0.79±0.18 [0.63–0.95]	<0.001*	26.18
Concentric Time (sec)	9.89±0.30 [9.62–10.15]	1.32±0.33 [1.031–1.609]	<0.001*	27.18
*p<0.05				

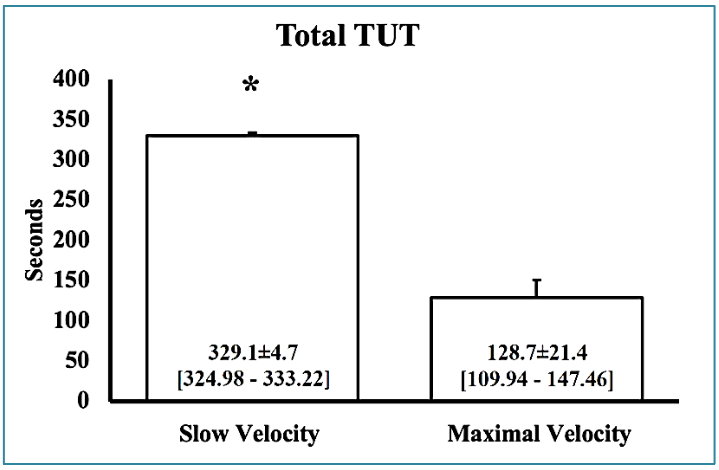

Fig-1: Comparison of total time under tension (sec) for all training sessions for both slow tempo and maximal velocity resistance exercise protocols (X±SD; *p<0.05; Hedge's g=12.94)

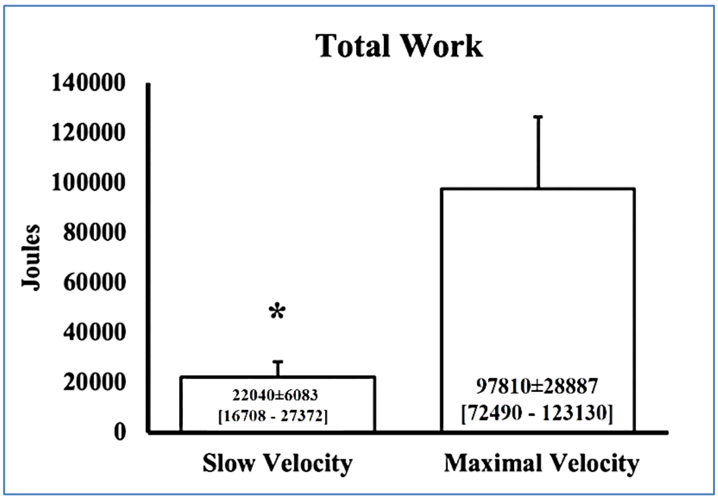

Fig-2: Comparison of mechanical work (J) for all training sessions for both slow tempo and maximal velocity resistance exercise protocols (X±SD; *p<0.05; Hedge's g=3.63)

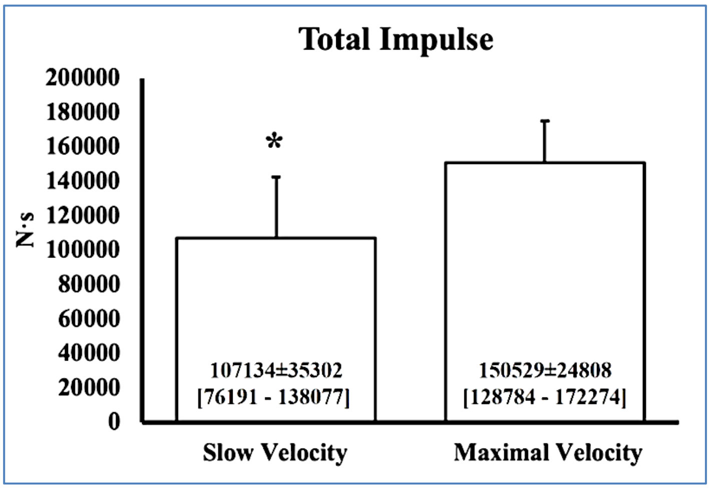

Fig-3: Comparison of impulse (N·s) for all training sessions for both slow tempo and maximal velocity resistance exercise protocols (X±SD; *p<0.05; Hedge's g=1.42)

DISCUSSION

Kinetic and kinematic properties of the SLOW resistance exercise protocol were significantly different from the MAX protocol. Both SLOW and MAX resistance exercises exhibit identical movement patterns except for lifting velocity. However, some of the biomechanical arguments used to support the use of SLOW resistance exercise are not correct. Since momentum is defined as mass x velocity, SLOW resistance exercise reduces momentum. Additionally, in SLOW resistance exercise the load is reduced (McGinnis, 2005), resulting in lower levels of force (Schilling *et al.*, 2008). It should be noted that the velocities observed for the MAX resistance exercise protocol were in the expected range for the loads used, whereas the SLOW group used considerably lower velocities than what is possible for their respective intensity (González-Badillo & Sánchez-Medina, 2010; Mann, 2016). In the present study, the MAX protocol included 3x10 repetitions at 70% 1RM for the squat followed by 3x10 repetitions at 70% 1RM for the bench press. The SLOW protocol included 1x10 repetitions at 28% 1RM for the squat followed by 1x10 repetitions at 28% 1RM for the bench press. All the following points of discussion are based on comparing these two commonly prescribed protocols.

Despite the obvious biomechanical differences, claims are still made as to why SLOW resistance exercise should be preferred over MAX resistance (Westcott, 1999). One is that SLOW resistance exercise creates longer periods of muscle tension, also known as time under tension. The second is that more muscle force is produced at slow speeds (Westcott, 1999). However, it should be noted that as shown in the present study, the low relative intensity of the SLOW resistance exercise produces less muscle force due to the small mass that could be used, and the low levels of acceleration purposely produced. The concept that SLOW training produces greater force are based on commonly reported force-velocity curves derived from isokinetic data (Schilling *et al*., 2004). The validity of this interpretation of a force-velocity curve requires a maximal effort contraction, not a submaximal velocity contraction such as used in SLOW resistance exercise (Schilling *et al*., 2004). The present study clearly demonstrated that, due in part to each repetition lasting longer; the relative intensity was so low that the forces remained low. Another argument used to promote SLOW resistance exercise is that low velocities reduce the momentum of the load (Westcott, 1999). Although this statement is true, as observed in the present study, it has been clearly demonstrated that greater increases in momentum are necessary for greater levels of force (McGinnis, 2005; Schilling *et al*., 2004). Since force= mass x acceleration, and momentum= mass x velocity, and the external load being lifted remained constant throughout the exercise, then the only way to increase the force produced is to increase the acceleration (and the velocity), and thus increase the momentum. Another claim for SLOW resistance exercise is that it produces more muscle power (Westcott, 1999). Power is defined as the product of force x velocity (McGinnis, 2005; Schilling *et al*., 2004). Therefore, if force is low and velocity is low, the resultant power will also be low. The results from the present study clearly demonstrate significantly lower power production during the SLOW protocol compared to the MAX protocol.

An interesting finding of this study is that although the SLOW protocol had greater TUT, the MAX protocol produced significantly greater values for the more commonly used biomechanical measures of work and impulse. While many proponents of intentionally slow velocity resistance exercise advocate the importance of greater TUT (Brzycki, 1995; Hutchins, 1992; Smith, n.d.; Westcott, 1999; Westcott *et al.*, 2001; Winnett & Carpinelli, 2001), this measure completely ignores the actual muscular forces and velocities produced and distances the resistance is moved during the exercise. Since mass, force (mass x acceleration), velocity, acceleration, distance and time are contributing factors to work and impulse, it is suggested that these may be more valuable variables to monitor during resistance exercise training sessions. If these measures are adopted, then the value of a particular resistance exercise training protocol would not be determined solely by the TUT.

It has been argued that SLOW resistance exercise is an effective way to train athletes (Brzycki, 1995; Carpinelli *et al*., 2004; Hutchins, 1992). It should be noted that many athletic movements require strength, power, and speed. A SLOW resistance exercise training session such as used in the present study requires lifting external loads between 25-50% 1RM (Hunter *et al*., 2003; Keeler *et al*., 2003; Kim *et al*., 2011; Rana *et al*., 2008; Wickwire *et al*., 2009). In sports where high power, strength, and speed is required, athletes need to be able to produce high levels of muscle force and power, and high contraction velocities. If SLOW resistance exercise is the only form of resistance exercise the athlete performs, then they are not training in a manner designed to enhance strength, power, or speed (Zatsiorsky *et al*., 2020).

Another reason suggested for using SLOW resistance exercise is that it supposedly produces less muscle damage while performing the same amount of work (Westcott, 1999). Conversely, more recent lay literature has claimed increased muscle trauma is a desired benefit of slow tempo resistance exercise (Smith, n.d.). Mechanical work is defined as force x distance (McGinnis, 2005), and if force is low and distance remains the same as in the present study, the total amount of work will be low. The present study demonstrated the MAX protocol produced significantly more work than the SLOW protocol. This suggests that although SLOW resistance exercise is challenging to perform, it results in considerably less mechanical work when compared to MAX resistance exercise. Although never scientifically studied to the authors' knowledge, it stands to reason that if differences exist for muscle tissue disruption between both types of training, it may be due to differing amounts of mechanical work. We acknowledge that our sample size was not large, however, where significant differences were identified the magnitude of dissimilarities was so large that statistical power was adequate. Further research is required to confirm this reasoning.

CONCLUSION

In conclusion, SLOW resistance exercise produces less velocity, force, mechanical work, and power when compared to MAX resistance exercise. However, the total amount of time under tension was greater with the SLOW resistance exercise compared to the MAX protocol for the entire training sessions. Thoughtful consideration of all factors should be made when designing a resistance training program. It is likely that SLOW resistance exercise may play a role in some resistance exercise programs. However, based on training specificity principles, if the primary goal of a resistance exercise training program is to improve muscular force and power, or it is to perform greater amounts of work, than MAX resistance training methods would be preferred.

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