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Optimizing Power Output by Varying Repetition Tempo

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OPTIMIZING POWER OUTPUT BY VARYING REPETITION TEMPO

A Master's Thesis presented to the Faculty of the
Graduate Program in Exercise and Sport Sciences at
Ithaca College

In partial fulfillment of the requirements for the degree
Master of Science

by

Riana Czapla

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Ithaca College
School of Health Sciences and Human Performance
Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Thesis of
Riana Czapla
submitted in partial fulfillment of the requirements for the degree of
Master of Science in the School of Health Sciences and Human Performance
at Ithaca College has been approved.

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ABSTRACT

This study investigated how varying interrepetition rest and eccentric velocity affected power output and the number of repetitions performed during a set of bench press. Subjects were 24 resistance trained males recruited from Ithaca College. Subjects completed 1 repetition maximum (1 RM) testing and on six subsequent days completed a set of bench press at 80% 1 RM until failure. Each set of bench press was at a different tempo involving varying eccentric phases (1 or 4 s), bottom rest (0 or 3 s), and interrepetition rest (0 or 4 s) intervals. A reflective marker on the bar tracked positional data to measure repetitions, peak power output, average peak power, maximum mean power, and average mean power. Each dependent variable was analyzed using a repeated measures ANOVA. The significance level for all analyses was set at $p \leq 0.05$. The results showed tempos with short eccentric phases and no bottom rest produced significantly greater repetitions and concentric power than all other tempos. Interrepetition rest did not significantly affect any variable. The combination of greater repetitions and higher power implies greater volume of work was completed with tempos containing short eccentric phases and no bottom rest intervals. Using such a repetition tempo during chronic resistance training may lead to greater strength and power gains. Future studies should investigate the effect of repetition tempo and interrepetition rest during chronic resistance training, training with multiple sets of exercise, or lifting with a lower intensity. In addition, athletes should use tempos with short eccentric phases and no bottom rest to maximize performance during acute testing.

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Thank you to all my subjects for their enthusiasm and participation.

DEDICATION

This thesis is dedicated to my mother, Dorinda Czapla,

for her support, patience, and encouragement

throughout my academic career.

Thanks Mom.

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Chapter 1

INTRODUCTION

Tempo training is a relatively new concept in resistance training that involves manipulating the timing of eccentric and concentric phases, along with rest intervals between the two. Altering tempo during resistance training may affect training outcomes and it is suggested that faster tempos lead to increases in power while slower tempos are beneficial for strength gains (Aaberg, 2007). However, the potential for specific timing of each tempo phase facilitating the desired outcomes of the training program is a topic requiring further study. Tempo is commonly described by a number (e.g., 40-3) with each digit representing time in seconds for the specified phase (i.e., eccentric, bottom rest, concentric, interrepetition rest) of the repetition. The dash for the concentric phase represents maximal speed.

The eccentric phase of a repetition involves lengthening of the muscle while shortening tension is developed. The eccentric phase of a repetition is the first digit in the tempo number. Superslow resistance training involves lengthening concentric and eccentric phases during a repetition to approximately 10 s and 5 s, respectively. Some researchers determined that superslow training, when compared to traditional resistance training, leads to equal improvements in strength (Keeler, Finkelstein, Miller, & Fernhall, 2001; Neils, Udermann, Brice, Winchester, & McGuigan, 2005). Others found greater strength improvements with traditional movement velocities (Rana et al., 2008), while one study found much greater improvements in strength with slow speed of contraction (Westcott et al., 2001). Accordingly, consensus is not available on how changing eccentric and concentric movement velocity affects strength and power output during a set of resistance exercise. In fact, changing eccentric velocity without also altering concentric velocity has not yet been studied.

Faster tempos with no rest between the eccentric and concentric phases should maximally activate the stretch-shortening cycle (SSC). The SSC involves eccentric stretch of a muscle followed immediately by a powerful concentric contraction of the muscle (Malisoux, Francaux, Nielens, & Theisen, 2006). The SSC is said to utilize stored energy from the eccentric phase to maximize concentric power. Cronin, McNair, & Marshall (2001) determined that performing an eccentric contraction prior to the concentric contraction resulted in a higher mean power output than performing only a concentric contraction. A longer rest interval between the eccentric and concentric phases of a repetition should inhibit the SSC, and therefore power output during the concentric phase. The rest interval at the bottom of a repetition is the second digit in the tempo number.

In order to maximize power production, the tempo must include a fast concentric phase. The concentric phase of a repetition should involve a powerful contraction in a short period of time. It mimics explosive movements commonly seen in activities such as jumping and throwing. As the speed of concentric contraction increases, greater power is developed at any given resistance.

As a set of exercise is performed, power output of each succeeding repetition tends to decrease (Lawton, Cronin, & Lindsell, 2006). Interrepetition rest may delay this decrease in power. The interrepetition rest (rest at the top of the repetition) is the final digit in the tempo number. In an attempt to maximize set power, Lawton et al. manipulated tempo to allow rest between each repetition for 23 s, every other repetition for 56 s, or every third repetition for 118 s. All three conditions produced a greater power output than the no rest, continuous lifting condition. However, the three rest groups were not significantly different from each other.

For practical purposes, time efficient resistance training should never involve interrepetition rest intervals of 23 s or more. Casual observation of weight lifters reveals short interrepetition rest that rarely exceeds 3-5 s. A typical set of exercise of six to eight repetitions takes approximately 12-16 s at a fast tempo while a slower tempo may take up to one minute. Both of these tempos have practical application unlike sets of 3-4 min as seen in the study by Lawton et al. (2006).

Much of the previous research on repetition tempo makes use of isokinetic dynamometers (Farthing & Chilibeck, 2003; Lacerte, deLateur, Alquist, & Questad, 1992; Shepstone et al., 2005). This work is informational but somewhat impractical because isokinetic equipment is expensive, difficult to set up, and generally inaccessible. There is, however, widespread availability of free weights and resistance training machines. Therefore, repetition tempo needs to be studied using isotonic contractions with commonly available equipment to determine efficient and effective resistance training protocols.

Statement of Purpose

The purpose of this study was to investigate how simultaneously varying rest and eccentric velocity (i.e., repetition tempo) affect power output and the number of repetitions performed during a set of bench press using free weights.

Hypothesis

The hypotheses of this study were:

1. Greater interrepetition rest would produce greater peak and mean concentric power and increase the number of repetitions during a set of bench press.
2. A decrease in eccentric velocity would produce less peak and mean concentric power (due to attenuation of the SSC and greater eccentric time under tension).
3. An increase in bottom rest interval would produce less peak and mean concentric power (due to attenuation of the SSC).

Assumptions of Study

The following assumptions were made for this study:

1. The subjects exerted maximal effort during each of the testing sessions.
2. The subjects were representative of resistance trained, college-aged students.
3. An increase in concentric power output is desirable because it leads to an increase in hypertrophy with training.

Definitions of Terms

The following terms were defined for the purpose of this study:

1. Peak Power Output– the highest peak concentric power output of all repetitions in a set of bench press.
2. Average Peak Power – the average concentric peak power of all repetitions in a set of bench press.
3. Maximum Mean Power – the highest mean concentric power output of all repetitions in a set of bench press.

4. Average Mean Power – the average concentric mean power of all repetitions in a set of bench press.
5. Resistance Trained – regular involvement in resistance training at least two times per week for the past six months.
6. Eccentric Phase – the muscular lengthening phase of a bench press repetition.
7. Concentric Phase – the muscular shortening phase of a bench press repetition.
8. Interrepetition Rest (Top Rest) – the delay between each repetition in a set of bench press with the elbow in full extension.
9. Bottom Rest - the delay between the eccentric and concentric phase of a bench press with the elbow in flexion.
10. Repetition Tempo – the pace at which the four phases (eccentric, bottom rest, concentric, top rest) are performed with a specific time for each phase.

Delimitations

The delimitations of this study were:

1. The subjects were college-aged, male resistance trained students.
2. The resistance exercise used was the bench press.
3. The studied repetition tempos only modified the eccentric, bottom rest, and interrepetition rest intervals in six specified rhythms (i.e., 10-3, 13-3, 10-0, 13-0, 40-0, 40-3).
4. Average peak and mean concentric power were calculated using Newtonian mechanics based on measured kinematic and inertial data.

Limitations

The limitations of this study were:

1. Generalization of these results may be limited to college-aged, resistance trained males.
2. Generalization of these results may be limited to bench press and not other resistance exercises.
3. A repetition tempo other than the six studied may produce different power output or repetition results.
4. Generalization of these results may be limited to power as calculated using Newtonian mechanics based on measured kinematic and inertial data.

Chapter 2

REVIEW OF LITERATURE

Introduction

A primary goal of resistance training is to improve performance by increasing strength and power production. Power production is a requirement in many sport tasks including running, throwing, and jumping and can be developed through strength training. Strength training variables that can affect power production include type and speed of contraction, and interrepetition rest intervals. These topics are relevant to repetition tempo, the speed and duration of phases of a repetition, and are reviewed and presented in this chapter. The specific topics for this chapter are: (1) Eccentric and Concentric Training, (2) Velocity of Training, and (3) Rest Intervals and Performance.

Eccentric and Concentric Training

Both eccentric and concentric contractions are commonly used during resistance training and sport situations. Eccentric contraction involves the lengthening of a muscle while producing tension. The opposite is concentric contraction, which shortens the muscle while producing tension. Training studies have focused on power output and strength gains with each type of contraction.

Testing differences between eccentric and concentric contractions has allowed a further understanding of strength properties. At all speeds, eccentric peak torque is greater than concentric peak torque (Drury, Stuempfle, Mason, & Girman, 2006; Norrbrand, Fluckey, Pozzo, & Tesch, 2008; Shepstone et al., 2005). The speed of contraction affects concentric but not eccentric torque. An acute study by Drury et al. tested 11 males at 90°, 180°, and 300°/s and found peak eccentric torque was equal across the three speeds while peak concentric torque was greater at 90°/s than 180°/s. Therefore, peak eccentric torque does not change with speed while peak concentric torque decreases with increasing speed.

Strength gains are often attributed to muscular hypertrophy. Training using eccentric contractions leads to greater total hypertrophy than solely using concentric contractions. Increases in muscle area are reported at 11% (Vikne et al., 2006), 3.5% (Seger, Arvidsson, & Thorstensson., 1998), 13% (Farthing & Chilibeck, 2003), 25% (Hather, Tesch, Buchanan, & Dudley, 1991) and 6.6% (Higbie, Cureton, Warren, & Prior, 1996) after eccentric training of the elbow or knee. Several studies (Farthing & Chilibeck; Seger et al.; Vikne et al.) showed no hypertrophy after concentric training although studies by Higbie et al. and Hather et al. revealed 5% and 20% increases in muscle size after concentric training, respectively. Collectively, these results lead to the conclusion that eccentric training consistently produces greater muscular hypertrophy than concentric training.

Total muscle area changes are dependent on hypertrophy of each muscle fiber type. Mixed results were found among several fiber type studies of eccentric vs. concentric training. No increases in Type I fiber area were noted in two studies (Mayhew, Rothstein, Finucane, & Lamb, 1995; Seger et al. 1998), after concentric or eccentric training. However, Hather et al. (1991) observed a 14% increase in Type I fiber area after eccentric training. Vikne et al. (2006) reported a 25% increase in Type I fiber area after eccentric training but a 2% decrease after concentric training. This difference between the studies may be due to the length of the training programs. Subjects in the latter two studies participated in training for 12 (Vikne et al.) and 19 (Hather et al.) weeks while only 4 (Mayhew et al.) and 10 (Seger et al.) weeks were used in studies not finding hypertrophy. In any case, however, type I fiber hypertrophy was only seen with an eccentric training program.

Differences in Type II fiber area are more pronounced after training than Type I fiber area. Concentrically trained men had a significantly greater Type II fiber area post-training than eccentrically trained men after four weeks of isokinetic knee extensions (Mayhew et al., 1995). However, Hather et al. (1991) found a statistically greater increase (32%) in Type II area with eccentric training compared to a 27% increase with concentric training. Vikne et al. (2006) agreed that eccentric training yielded more Type II fiber hypertrophy and reported a 40% increase in Type IIa fiber area after eccentric training compared to only a 5% increase after concentric training. In summary, Type I fiber area may only increase after eccentric training but Type II fibers apparently adapt to both eccentric or concentric training.

Neural adaptations are also responsible for increases in strength. One study trained subjects for six weeks with unilateral eccentric plantarflexion of the ankle (Mouraux, Stallenberg, Dugailly, & Brassinne, 2000). Neural adaptations were the only reason reported for increases in strength for both eccentric and concentric peak torque. Support of this claim comes from testing the non-trained limb which served as the control and showed improvements of 22%, 24%, and 25% in eccentric peak torque and 16%, 24%, and 22% in concentric peak torque at 30°, 60°, and 90°, respectively. This duration of training may have been long enough to produce neural adaptations, but too short to see changes in muscle fiber area.

Training Mode Specificity

Training mode specificity refers to better performances recorded with similar, rather than dissimilar, training and testing modes. This applies to eccentric resistance training in that eccentrically trained subjects performed better on eccentric than concentric testing. Eccentric training at 160°/s led to increases in eccentric force at 60°, 120°, and 180°/s by 27.5%, 34.1%, and 25.1%, respectively, but concentric testing at the same velocities showed no improvement for eccentrically trained subjects (Duncan, Chandler, Cavanaugh, Johnson, & Buehler, 1989).

Training eccentrically led to improvements in eccentric torque by 36.2% while concentrically trained subjects only improved 12.8% (Higbie et al., 1996). Similarly, training with concentric contractions led to an increase of 18.4% in concentric torque while eccentrically trained subjects only improved by 6.8% (Higbie et al.). Another study (Vikne et al., 2006) yielded 26% increased eccentric strength for eccentrically trained subjects while concentrically trained subjects only improved 9%. In summary, training eccentrically leads to the greatest eccentric testing performances, while training concentrically results in greatest improvements during concentric testing. Mode specificity applies to improved strength for both eccentric and concentric training.

Stretch Shortening Cycle (SSC)

It is difficult to find instances in sports when a concentric action is not preceded by a lengthening, eccentric action. When used together, the eccentric movement allows for a greater concentric power output due to the SSC (Cronin et al., 2001). The SSC is present in resistance exercises that begin with an eccentric contraction followed immediately by the concentric phase, such as the bench press.

Cronin et al. (2001) studied a variety of bench press techniques to determine how to develop the greatest concentric power output. Studying the use of bench press throws and rebound actions showed that the most effective way to produce concentric power was to incorporate both a rebound and throw at the end of the concentric contraction. The rebound action is the concentric phase following an eccentric phase. Repetitions that implemented a rebound had an 11.7% higher mean power output than only lifting with a concentric phase. Allowing the subject to throw the bar at the completion of the concentric phase increased the mean power output by 5.8% and peak power output by 9.1%. Thus, the SSC and fully accelerating the bar maximizes concentric power output.

Another study of the SSC tested 25 male subjects after 12 weeks of training to determine force improvements at high and low velocities (Lacerte et al., 1992). The training groups included isokinetic concentric and/or eccentric exercises at fast (180°/s) and slow (60°/s) speeds. Tested isokinetically, peak torque gains were greatest in the groups that performed an eccentric prior to a concentric contraction as compared to the concentric only groups. This training study demonstrated that using the SSC led to greater torque gains than training without incorporating the SSC.

Velocity of Training

While training with fast speeds may increase concentric power, training with slower speeds may also be beneficial. Strength, power, hypertrophy, and repetitions during resistance training are affected differently by fast and slow movement velocities. Training velocity specificity has been studied to determine optimal training velocities to improve strength and power.

Training Velocity Specificity

Training with eccentric contractions led to more velocity specific improvements in performance compared to training with concentric contractions. Seger & Thorstensson (2005) trained 10 subjects with pure eccentric or concentric contractions at 90°/s. When eccentrically trained subjects were tested at the same speed, peak eccentric torque and mean concentric torque significantly improved by 43% and 13%, respectively. No significant improvements for any measurement were noted at 30° or 270°/s. The only improvements after eccentric training occurred at the same testing speed, which suggests evidence of training velocity specificity. Concentrically trained subjects significantly improved mean concentric torque at all velocities and mean eccentric torque at 30° and 90°/s. Therefore, training velocity specificity was not applicable to concentric training.

Seger et al. (1998) reported contradictory results in that subjects eccentrically trained at 90°/s improved eccentric peak torque at 30° and 90°/s, as well as 90°/s for concentric peak torque. Concentrically trained subjects increased both concentric and eccentric torque at 30° and 90°/s. In this study, neither eccentric nor concentric training led to velocity specific improvements. Similarly, Duncan et al. (1989) reported significant improvements in eccentric torque across three speeds after eccentric training at 160°/s. Due to conflicting results, training velocity specificity is not yet fully understood.

Other Training Effects

Researchers compared 115 untrained subjects after six weeks of training with bicep curls at 80% one repetition maximum (1RM) with one or three sets at fast and slow velocities. The fast velocity used 1 s eccentric and concentric phases while the slow velocity consisted of 3 s eccentric and concentric phases. Subjects who trained at the faster velocity elicited 11% greater gain in elbow flexor concentric strength than the slower velocity (Munn, Herbert, Hancock, & Gandevia, 2005).

In another study, twelve subjects performed eight weeks of fast or slow isokinetic eccentric elbow flexion training (Shepstone et al., 2005). Faster velocity (3.66 rad/s) increased maximum torque more than slower velocity training (0.35 rad/s). This agreed with Munn et al. (2005) but contradicts the findings of Lacerte et al. (1992) who reported equal torque increases with fast (180°/s) and slow (60°/s) velocities. It is still unclear as to whether or not training at certain velocities are more beneficial to increase peak torque or force.

Murray et al. (2007) studied the effect of velocity training on power of the knee extensors as determined with a standing long jump. After four weeks of isokinetic training, power for both fast (400°/s) and slow (60°/s) velocities increased significantly and equally. Most previous research did not study angular velocities exceeding 180°/s even though most sport movements easily exceed this speed. Training at higher velocities was thought to benefit athletes based on velocity specificity adaptation (Murray et al.). However, this notion of specificity was not supported since training isokinetically at 400°/s did not lead to greater power when tested at that speed than the slower velocity. It is still not clear if other speeds between 180° and 400°/s would increase power. Further research should be performed to study faster velocities.

In contrast to these results, Morrissey, Harman, Frykman, & Han (1998) studied 24 untrained women who performed seven weeks of squat exercises with 1 s (fast group) or 2 s (slow group) eccentric and concentric phases at 8 RM resistance. Horizontal long jump distance increased 44% in the fast group but only 31% in the slow group. Other variables such as peak torque, and peak and average power did not differ between the two training velocities which is similar to the results reported by Murray et al. (2007).

Varying velocity may also affect muscular hypertrophy. Thirty-six untrained men and women performed isokinetic elbow extensions, concentrically with one arm and eccentrically with the other, at speeds of either 30° or 180°/s. Eccentric training at the faster velocity significantly caused greater hypertrophy (13%) than concentrically training at fast (2.6%) or slow velocity (5.3%). Eccentric training at a slow velocity also led to hypertrophy (7.8%) but this was not significantly greater than the concentric group (Farthing & Chilibeck, 2003). Accordingly, performing fast eccentric contractions may be the most beneficial to hypertrophy.

Repetitions

An acute study performed by Sakamoto & Sinclair (2006) compared moving at four velocities: maximal velocity, 1.0, 1.4, and 2.8 s per eccentric and concentric phase. Each velocity was tested at 40%, 50%, 60%, 70%, and 80% 1 RM to determine the effect of velocity movement on the number of maximal bench press repetitions. Increasing movement velocity led to an increased number of repetitions, however, no difference was seen between maximal and 1 s contraction velocities. Using these results, the authors compiled a chart allowing for prediction of the maximal number of repetitions based on the percentage of 1RM weight lifted.

Resistance Intensity

Tanimoto & Ishii (2006) used 24 trained men to compare the effects of velocity and load intensity on strength and muscle cross-sectional area. The slow, low intensity group (LST) performed exercises at a tempo of 3 s for the concentric and eccentric phases at 50% 1RM. The normal speed, high intensity group (HN) performed lifts at a tempo of 1 s for concentric and eccentric phases at 80% 1RM. The normal speed, low intensity group (LN) performed lifts at a tempo of 1 s for concentric and eccentric phases, at 50% 1RM. LST and LN groups performed at equal intensities and work volume but different velocities. After the completion of a 12 week leg extension program, isometric strength of the LST group was significantly higher than the LN, but not as high as the HN group. No significant differences in isokinetic strength were observed between the groups although all groups increased 1 RM after training. LST and HN groups increased muscular size by 5.4% and 4.3%, respectively. This research supports the idea that slow resistance training develops greater isometric, but not isokinetic strength than traditional velocity training using the same intensity or resistance. Slow velocity, high intensity resistance training was not studied, however, this would allow for an equal comparison of training volumes instead of comparing differing programs. A future study should address this issue.

Superslow Resistance Training

Superslow resistance training uses prolonged eccentric or concentric phases during resistance training. One acute superslow study (Hatfield et al., 2006) used squat and shoulder press repetitions with 10 s concentric and eccentric phases compared to self-selected movement velocity. Results showed decreased concentric force, power output, volume of work, and number of repetitions completed for slow resistance training as compared to self-selected velocity. Greater rating of perceived exertion was also noted for the slow training group and the authors concluded there are no benefits of superslow training.

Researchers also studied superslow resistance training with shorter eccentric phases (Keeler et al., 2001; Neils et al., 2005). These studies compared training groups that performed 10 s concentric and 5 s eccentric phases to a traditional group paced at 2 s concentric and eccentric phases. Due to fatiguing elongated phases of concentric contraction, 60% 1RM was used for the slow group while the self-selected velocity group used 80% 1 RM. Keeler et al. had 19 subjects while Neils et al. had 14 subjects, and they trained for 10 and 8 weeks, respectively. Even though these studies both implemented general whole body exercises and used similar methodology, conflicting results were found.

Keeler et al. (2001) found traditional speed training improved the total weight lifted, as well as leg press, leg curl, leg extension, torso arm, and bench press strength more than the superslow velocity, although both groups improved from pre- to post-testing. On the other hand, Neils et al. (2005) found equal improvements between the two different training velocities. Improvements across velocities in squat strength for slow (3.6%) and fast (6.8%) velocities, and bench press strength for slow (9.1%) and fast (8.6%) velocities did not significantly differ. It is difficult to interpret these results because slower velocity training is likely at a disadvantage due to using a lower resistance. Further studies should compare different velocities with equal resistances.

Like Keeler et al. (2001), Rana et al. (2008) found greater improvements in leg strength for traditional over slow velocity training. As in previous studies, subjects used 10 s concentric and 4 s eccentric for the superslow velocity and 1-2 s concentric and eccentric phases for traditional velocity. In this study, however, all trained with 6-10 RM or 6 weeks. These authors concluded that traditional speed resistance training was more effective than superslow training (Rana et al.).

On the other hand, Wescott et al. (2001) determined that superslow resistance training led to greater improvement in strength than traditional velocity. Subjects (n=147) completed a 10 week exercise program with a 13 station circuit. The slow velocity group performed 4-6 repetitions at each station at a speed of 4 s eccentric and 10 s concentric, while the traditional group performed 8-12 repetitions at a speed of 4 s eccentric and 2 s concentric. Subjects were tested at their training speed throughout the study. Slower velocity training led to 50% greater strength gains in the bench press than traditional speed training. Total strength for all exercises increased 25% for traditional speed while slow speed increased 44%.

Rest Intervals and Performance

Tempo is a relatively new concept in resistance training that considers both the speed of contractions and rest intervals within a repetition. The velocity of the concentric and eccentric phases can be manipulated in an attempt to optimize power and strength. In theory, slow, controlled movements may be more beneficial to developing strength while faster movements may be more conducive to power production (Aaberg, 2007). However, there is a lack of research on tempo training, especially the rest intervals. Interrepetition rest intervals occur between the concentric and eccentric phases of a lift and may impact the power produced during resistance training. Researchers suspected increasing interrepetition rest would increase power production. While methods of studying rest intervals differ, a general consensus does confirm these suspicions (Byrd, Centry, & Boatwright, 1988; Lawton et al., 2006).

A set of continuously performed resistance exercise showed a decrease in power for every succeeding repetition (Lawton et al., 2006). In an attempt to prevent the decline in power, three interrepetition rest intervals were studied. A "singles group" rested 23 s between each repetition, a "doubles" group rested 56 s after every two repetitions, and a "triples" group rested 109 s between every third repetition. All sets were performed at 6 RM and every set lasted 118 s. The greatest power output occurred for the "triples" group, although it was not significantly different from either the "singles" and "doubles" groups. All three resting groups developed more power in a set than a continuous lifting group. As the rest interval increased, the power production during each following repetition also increased. Although interrepetition rest intervals of 23-109 s are extremely long for a typical weight training session, results show that an increase in rest also increases power production.

More practical rest intervals of 2 and 3 s were studied to examine power output and cardiovascular adaptations during circuit training (Byrd et al., 1988). The circuit involved a variety of lifts including seated military press, two-arm curls, leg press, bench press, weighted sit-ups, and leg curls. Subjects trained for 10 weeks using either continuous lifting, pausing for 1 s between repetitions, or resting for 2 s between repetitions. All groups performed each exercise for a total of 1 min. This caused a difference in the number of repetitions between groups as a shorter rest interval led to a greater number of repetitions performed. At the completion of training, strength increased in all groups with the greatest gain in leg press for continuous lifting. The authors concluded that rest between repetitions did not elicit greater strength increases than continuous lifting. If the training groups had used equal work volumes by completing the same number of repetitions, different results may have been observed.

Summary

Eccentric and concentric contractions elicit different improvements after resistance training. Mode specificity is apparent with both eccentric and concentric performance while speed specificity is present with eccentric training. Eccentric training appears to lead to greater muscle hypertrophy than concentric training. It is also clear that the SSC allows greater power production than a concentric effort alone.

Both isokinetic and isotonic resistance have been studied to understand the training effect of velocity of movements. It is uncertain if faster training velocities lead to greater strength gains than slower training velocities. Superslow resistance training has shown few benefits and has no practicality due to the lengthened time of each set. A flaw of many velocity studies relates to uneven training volumes. As the speed of contraction decreased, so did the training volume due to either fewer repetitions or less resistance. This causes difficulty when interpreting results across training groups. Additional research is needed to study movement velocities with equal workloads.

Movement velocities and rest intervals are both variables worthy of study because each can impact resistance exercise performance. Tempo is a concept that considers both concentric and eccentric movement velocities as well as rest intervals during a repetition. It would be useful to determine optimal resistance tempo for improving workout efficiency, strength, and power development.

Chapter 3

METHODS

This chapter describes the methods and procedures used in this study. The intention of the study was to determine how varying repetition tempo would impact concentric power output and the number of repetitions performed. Repetition tempo describes specific durations of eccentric, bottom rest, concentric, and interrepetition rest phases. Detailed subsections in this chapter include: (1) Subjects, (2) Experimental Design, (3) Procedures, (4) Data Collection, (5) Data Processing, and (5) Data Management and Statistics.

Subjects

The subjects for this study were recruited volunteers from the student population of Ithaca College. The subjects were 24 college-aged, resistance-trained males solicited via flyers posted in the Fitness Center and class announcements. A brief medical history form (Appendix A) was used to ensure ability to participate. The subjects needed to be regular weight lifters in good health and free of injury. Subjects were excluded from participating if acute or chronic injuries, illnesses, or other medical reasons existed that could endanger them or affect the outcome of the study. The study was approved by the Ithaca College Human Subjects Review Board and subjects who chose to participate were made aware of the risks, benefits, and protocols of the study while providing informed consent (Appendix B).

Experimental Design

The subjects came in for one day of preliminary testing and six days of experimental sessions, one for each tempo. The tempos included combinations of two different eccentric speeds, bottom rest, and interrepetition rest intervals. Preliminary testing involved a one repetition maximum (1 RM) bench press to determine the lifting resistance to be used during the six tempo sessions. Between each testing session, at least 48 h were allowed to help attenuate inter-session performance effects.

This study was a repeated measures design administered in a partially randomized and counterbalanced fashion across all six tempos. Half of the subjects were randomly assigned to complete the first three testing sessions using tempos A, D, and E, while the other half used B, C, and F during the first session. Within the first three sessions, the testing order of each tempo was counterbalanced. After the first three testing sessions, the group that started with the A, D, and E tempos completed the remaining B, C, and F tempos, and vice versa. Again, the tempos completed in the last three sessions were counterbalanced (see Table 1).

Procedures

Bench Press 1 RM Protocol

A Monark cycle ergometer was used for a 5 min warm-up with a resistance of 1 kp at a self-selected cadence before 1 RM testing. Within 1-2 min of completing the warm-up, subjects began 1RM testing as described by Baechle & Earle (2008). A consistent grip width was measured and maintained across all testing sessions. The subjects had their feet crossed and elevated above the bench to deter using their legs. A strap was placed around their waists to secure the subjects to the bench to prevent undesired accessory muscle movement.

The bench press 1 RM trial began with 3-4 repetitions at 80% 1 RM based on the subject's knowledge of his lifting ability. Resistance was increased to 90% 1 RM for 1-2

Table 1

Testing Session Orders

	Testing Order					
Subject	First	Second	Third	Fourth	Fifth	Sixth
1	B	F	C	A	E	D
2	D	E	A	C	F	B
3	F	B	C	E	A	D
4	A	E	D	B	C	F
5	B	C	F	A	D	E
6	A	D	E	B	F	C
7	B	F	C	A	E	D
8	D	A	E	C	B	F
9	D	E	A	C	F	B
10	F	C	B	E	D	A
11	E	A	D	F	C	B
12	E	A	D	F	C	B
13	C	B	F	D	A	E
14	E	D	A	F	B	C
15	F	B	C	E	A	D
16	A	D	E	B	F	C
17	C	F	B	D	E	A
18	A	E	D	B	C	F
19	E	D	A	F	B	C
20	C	F	B	D	E	A
21	F	C	B	E	D	A
22	D	A	E	C	B	F
23	C	B	F	D	A	E
24	B	C	F	A	D	E

repetitions, and then 100% estimated 1 RM was performed. A successful repetition was followed by a weight increase of 5 lbs while an unsuccessful repetition was reattempted. This process continued until 1 RM was determined. A 3-5 min rest was given between each attempt.

Tempo Trials

On arrival, subjects completed a 24 hour history form (Appendix C) and then performed the same warm-up with the same form as during 1 RM testing. To become familiar with the tempo of that training session, subjects completed 3-4 repetitions with 50% 1 RM to practice lifting to the cadance. Each of the six tempos consisted of four phases (eccentric, bottom rest, concentric, and interrepetition rest) measured in seconds (see Table 2). The dash in the concentric phase symbolizes maximal speed. The subjects performed the bench press tempo with pacing assistance by a metronome. Subjects were instructed to move the weight to the prescribed speed as closely as possible. The subjects continued performing repetitions of bench press until they experienced muscular failure. Failure occurred when subjects were physically unable to move the resistance, improper form was used to perform a repetition, or tempo clearly could not be maintained. Improper form included the use of accessory muscle movement (i.e., legs, back, or shoulders). Post-testing analysis further determined failure when two successive repetition tempo phases were more than one standard deviation from the mean time of all lifts within the set (Sakamoto & Sinclair, 2006). The number of completed repetitions was also recorded. These testing procedures were used for all six tempo testing sessions.

Table 2

Tempo Protocols

	Phase			
Tempo	Eccentric	Bottom Rest	Concentric	Interrepetition Rest
A	1	0	-	3
B	1	3	-	3
C	1	0	-	0
D	1	3	-	0
E	4	0	-	0
F	4	0	-	3

Note. Units of the phases are time in seconds. The dash in the concentric phase symbolizes maximal speed.

Data Collection

A normal speed 60Hz camera (NEC T1-23A, Tokyo, Japan) connected to a computer with an analogue to digital converter was used to capture the movement of a retro reflective marker placed on the end of the bench press Olympic bar. The camera was .87 m high and 4.5 m away from the close end of the bar, providing a 2 m by 3 m view of the sagittal plane of bar trajectory. A light was placed in line with the optical axis of the camera to illuminate the reflective marker for automatic digitizing. To determine calibration scale factors, a rectangular frame (.7112 m x .348 m) was held in line with the sagittal plane at the end of the bar, perpendicular to the camera. Peak Motus software (version 8.4.3, Peak Performance Technologies, INC., Centennial, Colorado) was used to capture the video in real time.

Data Processing

The path of the bar was automatically digitized using Peak Motus. Raw 2D coordinates were scaled and filtered using Quintic Spline processing using the default spline algorithm (Peak Motus). The processed 2D data were exported as text files to determine power, work, and temporal dependent variables in a custom program written in LabView (version 8.6, National Instruments, Austin, Texas).

Calculation of Power

Force was calculated using Newton's second law: **F** = **ma**. Acceleration of the bar in both x and y directions was calculated as the second derivative of position data over the entire repetition. The x-acceleration was multiplied by the mass of the bar to get the applied force acting on the bar in the x direction. The y-acceleration was multiplied by the mass of the bar and added to the weight to get the applied force acting on the bar in the y direction. Power was calculated using: **P** = **F** x **V** where force was the applied force calculated above and velocity was determined from the first derivative of the position data.

Determination of Start and Stop of Each Phase

The vertical component of the velocity data (Figure 1d) was filtered using a low pass 4th order Butterworth filter with a cutoff of 0.5 Hz (Figure 1e). Local vertical velocity minimums and maximums were found from these data to determine the midpoint of each repetition. Threshold values of greater than -0.1 m/s or -0.12 m/s for tempos A-D and E-F, respectively, were used for minimums while less than 0.15 m/s was used to find maximums. The filtered velocity had to be greater or less than the threshold for 45 data points to count as a local minimum or maximum, respectively.

The start of the eccentric phases was found by searching backwards from each local minimum through vertical velocity (Figure 1c) calculated from over-filtered position data (Figure 1b) filtered at a cutoff frequency of 1.5 Hz and 2 Hz for tempos A-D and E-F, respectively. The first data point that was greater than -0.05 m/s was the start of the eccentric phase. The end of the eccentric phase was determined by searching forward from each local minimum velocity for the first data point greater than -0.05 m/s.

The start of the concentric phase was found by searching backwards from each local maximum for the first data point less than 0.05 m/s. Similarly, the end of the concentric phase was determined by searching forward from each local maximum for the first data point less than 0.05 m/s (Figure 1c). The start and end of each phase was indicated on a graph of vertical position data (Figure 1a). Each trial was visually inspected and adjusted using an interactive graphing tool if the algorithm failed to find

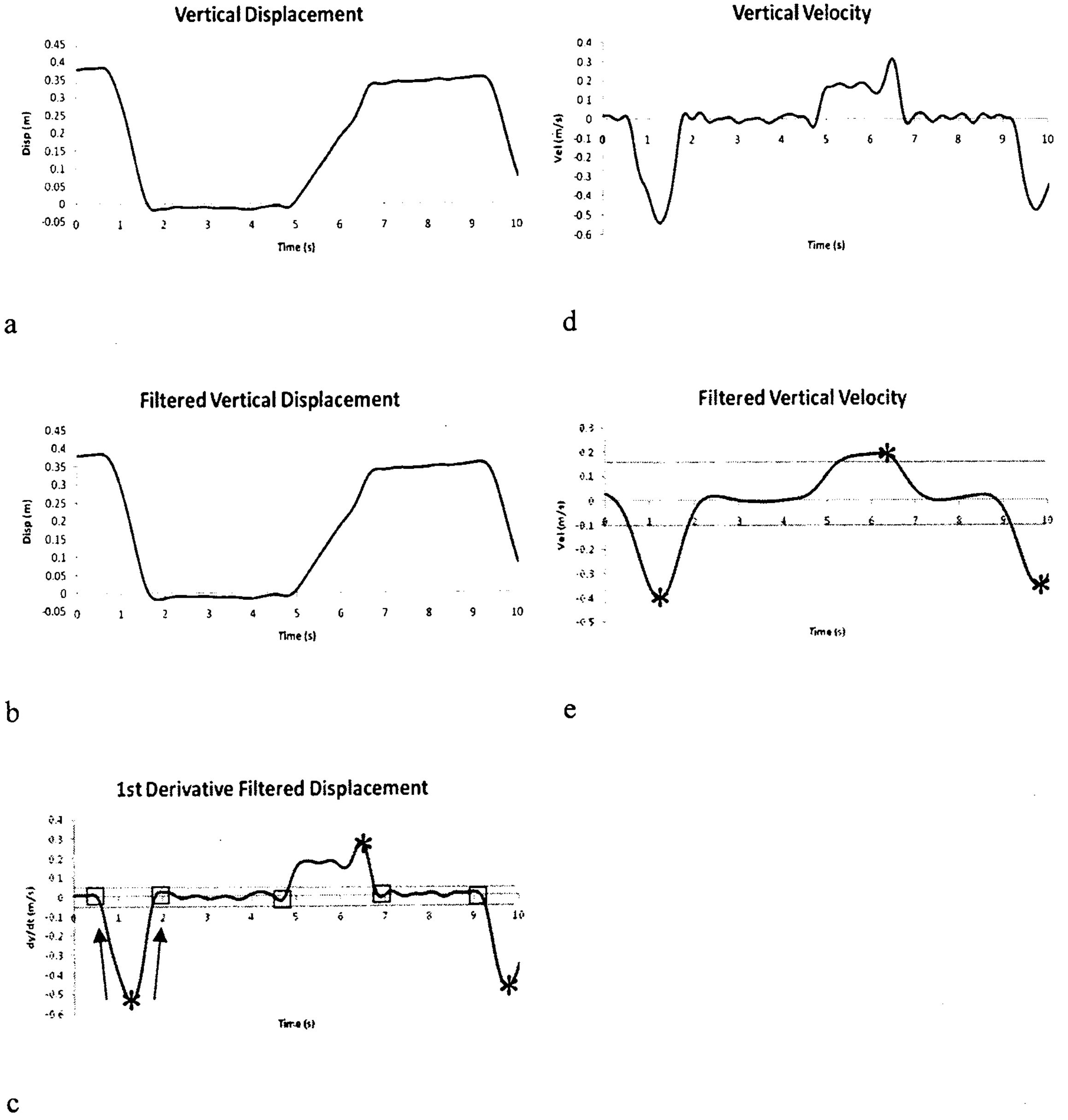

Figure 1. Raw, Filtered, and Derivative Data of Bar.

a. Raw positional data of bar

b. Filtered data from Figure a.

c. First derivative of Figure b. Used to calculate velocity in the power equation and find local starts and stops of each tempo phase.

d. First Derivative of Figure a.

e. Filtered data from Figure d. Used to find local velocity minimums and maximums to determine midpoints of each repetition.

the correct phases. This occurred for approximately one half of the trials.

Calculation of Time and Performance Variables

1. Peak Concentric Power - The maximum power value during the concentric phase of each repetition.
2. Peak Power Output - The greatest peak concentric power value from each trial.
3. Average Peak Power - The average of the peak concentric power values across all repetitions of a trial.
4. Mean Concentric Power - The average of the instantaneous power values of each concentric phase of each repetition.
5. Maximum Mean Power - The greatest mean concentric power value from each trial.
6. Average Mean Power - The average of the mean concentric power values across all repetitions of the trial.
7. Time of Each Phase - Calculated by subtracting the starting sample number from the stop sample number of each event and dividing by 60 to convert to seconds (e.g. Eccentric time = (stop eccentric sample – start eccentric sample) / 60 sec).
8. Average Time of Each Phase - The average time of each phase across all repetitions.

Data Management and Statistics

Multiple one-way analysis of variance (ANOVA) with repeated measures were completed to compare differences between the six tempos on the number of repetitions, peak power output, average peak power, maximum mean power, and average mean power. Significant F-values were further analyzed using a Tukey post-hoc assessment. When assumed sphericity was violated, a Greenhouse-Geisser analysis was implemented. All statistics were performed on SPSS with an alpha level set at 0.05.

Chapter 4

RESULTS

This chapter describes results from examining the effects of repetition tempo on aspects of concentric power output and the number of bench press repetitions performed. Statistical analyses of data collected are presented in this chapter and raw data can be found in Appendix D. Detailed subsections in this chapter include: (1) Subjects, (2) Repetition Phase Duration Data, and (3) Performance Variables.

Subjects

Subjects (n=24) were male resistance trained Ithaca College students who voluntarily participated in this study. Participants had an average of 4.9 ± 2.6 years of resistance training experience. Descriptive data are presented in Table 3. They were of typical height and weight for college-aged males. All subjects successfully completed all six repetition tempos at 80% 1RM with a mean 1 RM of 101.52 ± 19.9 kg.

Repetition Phase Duration Data

To ensure tempos were maintained throughout all repetitions, time to complete each phase (eccentric, bottom rest, concentric, interrepetition rest) was measured. Table 4 presents the desired and actual phase duration means and standard deviations. Subjects were instructed to perform concentric phases as quickly as possible and averaged 1.55 ± 0.3 s across tempos. All actual phase durations were maintained within 0.59 s of the desired duration. All repetitions were successful since timing failure, two successive repetitions more than 1 SD from the mean time of all repetitions in the set for any repetition tempo phase (Sakamoto & Sinclair, 2006), did not occur.

Table 3.

Subject Characteristics

	Height (cm)	Weight (kg)	Age (years)	1RM (kg)
Mean	176.27	83.96	20.67	101.52
SD	6.71	14.14	1.71	19.89

Note. 1 RM (Bench press 1 repetition maximum).

Table 4.

Phase Duration

Tempo	Phase	Desired Mean (sec)	Actual Mean ± SD (sec)	Min (sec)	Max (sec)
A	Eccentric	1	1.06 ± 0.21	0.70	1.42
A	Bottom	0	0.07 ± 0.10	0.02	0.45
A	Concentric	-	1.73 ± 0.16	1.03	1.73
A	Interrepetition	3	2.78 ± 0.24	2.44	3.33
B	Eccentric	1	1.31 ± 0.31	0.87	2.06
B	Bottom	3	2.65 ± 0.60	1.72	5.02
B	Concentric	-	1.69 ± 0.25	1.32	2.42
B	Interrepetition	3	2.86 ± 0.29	2.33	3.46
C	Eccentric	1	0.97 ± 0.12	0.71	1.18
C	Bottom	0	0.05 ± 0.05	0.02	0.25
C	Concentric	-	1.33 ± 0.15	1.16	1.66
C	Interrepetition	0	0.24 ± 0.21	0.03	0.93
D	Eccentric	1	1.26 ± 0.21	0.87	1.80
D	Bottom	3	2.41 ± 0.30	1.99	3.13
D	Concentric	-	1.64 ± 0.33	1.23	2.56
D	Interrepetition	0	0.18 ± 0.17	0.03	0.78
E	Eccentric	4	3.45 ± 0.53	1.60	3.44
E	Bottom	0	0.21 ± 0.47	0.04	0.06
E	Concentric	-	1.63 ± 0.26	1.12	2.00
E	Interrepetition	0	0.12 ± 0.10	0.04	0.01
F	Eccentric	4	3.68 ± 0.27	3.17	4.34
F	Bottom	0	0.10 ± 0.08	0.03	0.45
F	Concentric	-	1.68 ± 0.38	1.19	2.52
F	Interrepetition	3	2.84 ± 0.27	2.39	3.32

Note. Dash in the Desired Mean column indicates maximal speed.

Performance Variables

Repetitions

The number of successful bench press repetitions was measured for each tempo and a one-way ANOVA with repeated measures showed a statistically significant difference ($p \leq 0.000$) between the six tempo trials (Table 5). A Tukey post-hoc analysis revealed the number of repetitions for tempos A and C was statistically greater than tempos B, D, E, and F ($p \leq 0.000$). The number of repetitions for tempo A were 76.8%, 68.7%, 54.5%, and 70.0% greater than the number of repetitions for tempos B, D, E, and F, respectively. The number of repetitions for tempo C were 88.0%, 84.3%, 68.9%, and 85.8% greater than the number of repetitions for tempos B, D, E, and F, respectively. No significant differences were found between number of repetitions for tempos A and C nor between number of repetitions for tempos B, D, E, and F. Figure 2 illustrates the repetition results for the six tempos. In summary, more bench press repetitions were performed with tempos involving 1 s eccentric phases and no bottom rest intervals (i.e., A and C) than all other tempos.

Peak Power Output

Peak power output (PPO) is defined as the greatest concentric power of all repetitions in a set. A one-way ANOVA with repeated measures showed a statistically significant difference ($p \leq 0.000$) between the six tempo trials (Table 6). A Tukey post-hoc analysis revealed that tempos A and C had statistically greater PPO than tempos B, D, E, and F ($p \leq 0.000$). PPO for tempo A were 19.8%, 18.5%, 18.5%, and 26.4% greater than PPO for tempos B, D, E, and F, respectively. PPO for tempo C were 24.1%, 22.8%, 22.8%, and 30.1% greater than PPO for tempos B, D, E, and F, respectively. No

Table 5.

Repetitions: One-Way Repeated Measures ANOVA Summary Table

	SS	df	MS	F	p
Tempo	475.972	3.145	151.329	65.805	0.000*
Error	166.361	72.341	2.300		

Note. $^*p \leq 0.05$

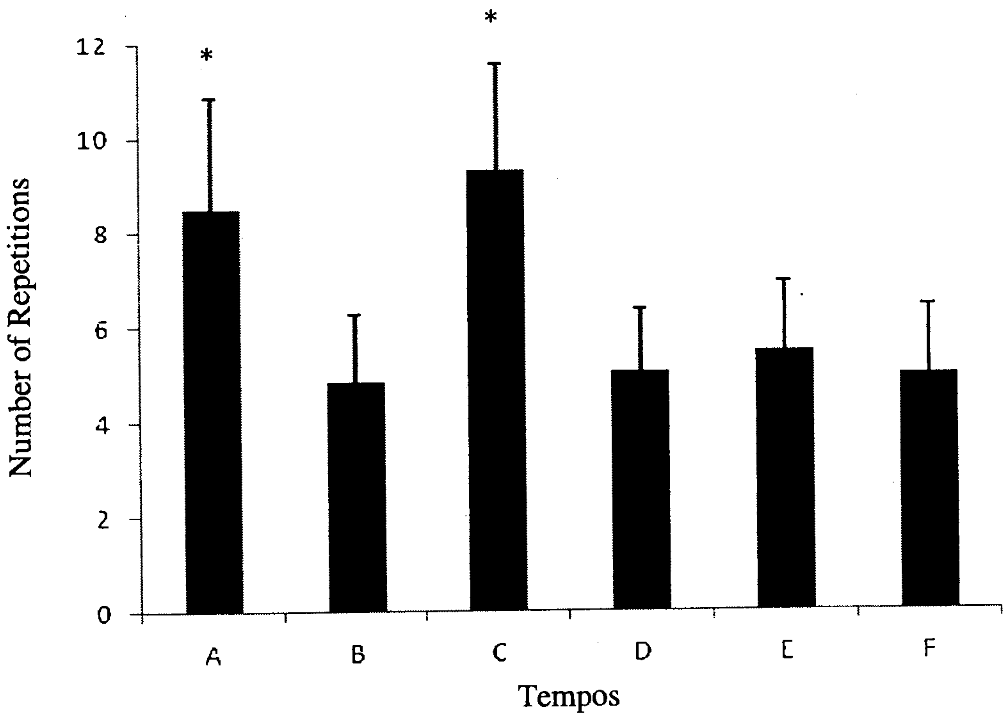

Figure 2. Repetitions - means and standard deviations (error bars). *Significant ($p \leq 0.05$) difference from tempos B, D, E, and F.

Table 6.

Peak Power Output: One-Way Repeated Measures ANOVA Summary Table

	SS	df	MS	F	p
Tempo	307316.285	5	61463.257	19.348	0.000*
Error	364641.273	115	3170.794		

Note. *$p \leq 0.05$

significant differences were found between tempos A and C nor between tempos B, D, E, and F. Figure 3 illustrates PPO results for the six tempos. In summary, greater peak power output was produced with tempos involving 1 s eccentric phases and no bottom rest intervals (A and C) than all other tempos.

Average Peak Power

The third performance variable examined in this study was average peak power (APP), which is defined as the average of the peak power values for all repetitions in a set. A one-way ANOVA with repeated measures revealed statistically significant differences ($p \leq 0.000$) between the six tempo trials (Table 7). Further evaluation using a Tukey post-hoc analysis showed tempos A and C produced greater APP than tempos B, D, E, and F ($p \leq 0.05$). APP values for tempo A were 21.2%, 18.0%, 20.4%, and 26.5% greater than APP values for tempos B, D, E, and F, respectively. APP values for tempo C were 20.3%, 17.2%, 19.5%, and 25.5% greater than APP values for tempos B, D, E, and F, respectively. No significant differences were found between tempos A and C nor between tempos B, D, E, and F. Figure 4 depicts the average peak power results for the six tempos. In summary, greater average peak power was produced with tempos involving 1 s eccentric phases and no bottom rest intervals (A and C) than all other tempos.

Maximum Mean Power

Maximum mean power (MMP) is defined as the greatest mean power value for all repetitions within a set. A one-way ANOVA with repeated measures revealed statistically significant differences ($p \leq 0.000$) between the six tempo trials (Table 8). A Tukey post-hoc analysis determined that tempos A and C produced greater MMP values

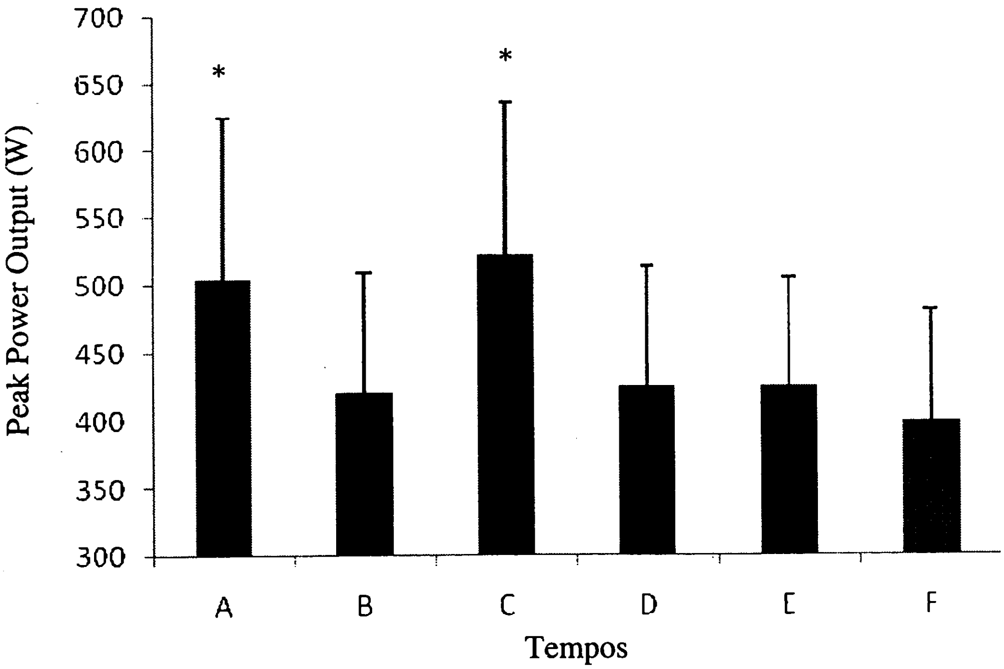

Figure 3. Peak Power Output - means and standard deviations (error bars). *Significant ($p \leq 0.05$) difference from tempos B, D, E, and F.

Table 7.

Average Peak Power: One-Way Repeated Measures ANOVA Summary Table

	SS	df	MS	F	p
Tempo	175282.831	3.042	57612.883	16.329	0.000*
Error	246892.551	69.976	3528.258		

Note. $*p \leq 0.05$

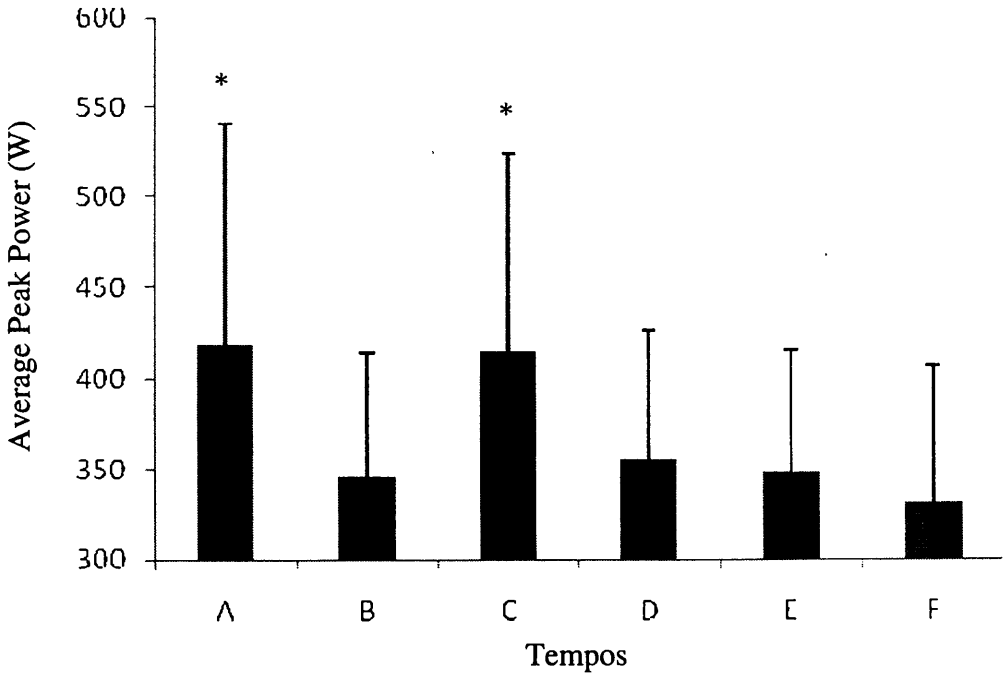

Figure 4. Average Peak Power - means and standard deviations (error bars). *Significant ($p \leq 0.05$) difference from tempos B, D, E, and F.

Table 8.

Maximum Mean Power: One-Way Repeated Measures ANOVA Summary Table

	SS	df	MS	F	p
Tempo	171946.692	3.504	49070.380	34.490	0.000*
Error	114663.104	80.594	1422.727		

Note. $*p \leq 0.05$

than tempos B, D, E, and F ($p \leq 0.05$). MMP values for tempo A were 26.8%, 22.7%, 21.2%, and 30.8% greater than MMP for tempos B, D, E, and F, respectively. MMP values for tempo C were 29.8%, 25.6%, 24.1%, and 33.8% greater than MMP values for tempos B, D, E, and F, respectively. No significant differences were found between tempos A and C nor between tempos B, D, E, and F. Figure 5 depicts the maximum mean power results for the six tempos. In summary, greater MMP was produced with tempos involving 1 s eccentric phases and no bottom rest intervals (A and C) than all other tempos.

Average Mean Power

The final performance variable measured in this study was average mean power (AMP) which is the average of all maximum mean power in a set. A one-way ANOVA with repeated measures revealed statistically significant differences ($p \leq 0.000$) between the six tempo trials (Table 9). A Tukey post-hoc analysis determined that tempos A and C produced greater average mean power than tempos B, D, E, and F ($p \leq 0.05$). AMP values for tempo A were 22.9%, 18.5%, 20.7%, and 25.1% greater than AMP values for tempos B, D, E, and F, respectively. AMP values for tempo C were 21.6%, 17.3%, 19.5%, and 23.9% greater than AMP values for tempos B, D, E, and F, respectively. No significant differences were found between tempos A and C nor between tempos B, D, E, and F. Figure 6 shows AMP results for the six tempos. In summary, greater AMP was produced with tempos involving 1 s eccentric phases and no bottom rest intervals (A and C) than all other tempos.

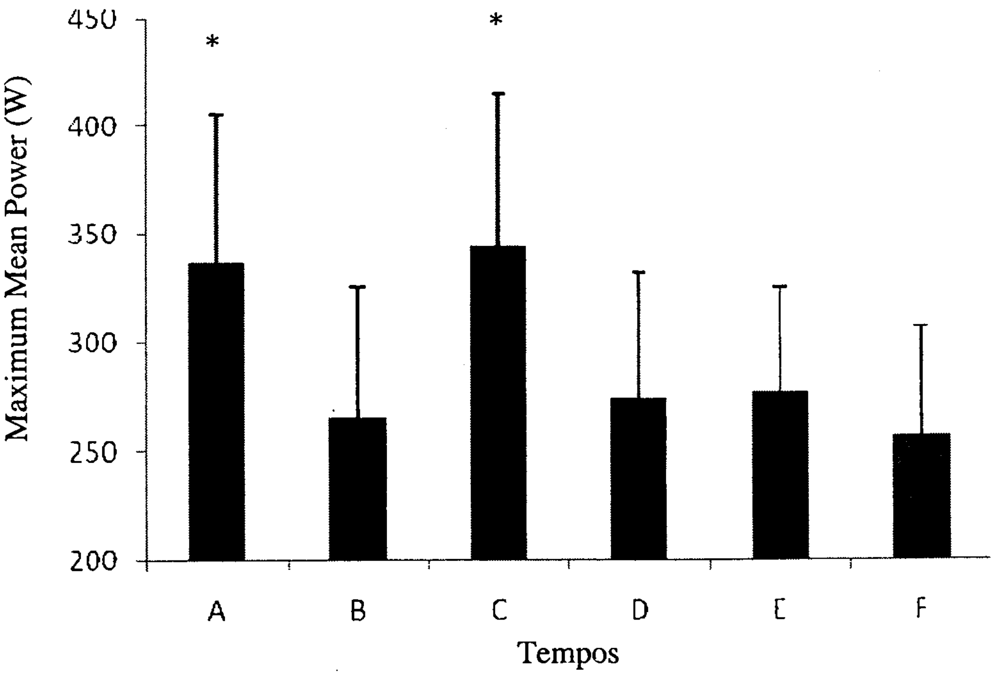

Figure 5. Maximum Mean Power - means and standard deviations (error bars).

*Significant ($p \leq 0.05$) difference from tempos B, D, E, and F.

Table 9.

Average Mean Power: One-Way Repeated Measures ANOVA Summary Table

	SS	df	MS	F	p
Tempo	63687.846	5	12737.569	21.833	0.000*
Error	67092.447	115	583.413		

Note. *$p \leq 0.05$

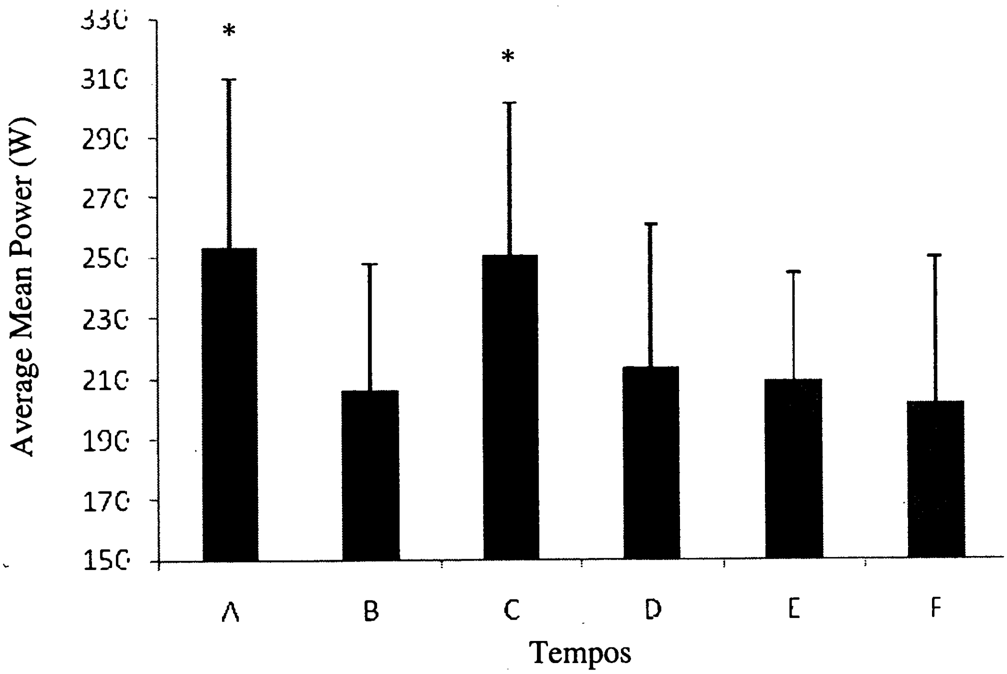

Figure 6. Average Mean Power - means and standard deviations (error bars).

*Significant (p ≤ 0.05) difference from tempos B, D, E, and F.

Summary

All dependent variables (i.e., repetitions, peak power output, average peak power, maximum mean power, and average mean power) for tempos with short eccentric phases and no bottom rest (A and C) were significantly greater than all other tempos (B, D, E, and F). There were no statistically significant differences between tempos A and C for any variable. Regardless of tempo, adding three seconds of interrepetition rest had no significant effect on any dependent variable.

Chapter 5

DISCUSSION

The primary purpose of this study was to determine the most effective bench press repetition tempo to create the greatest concentric power and number of repetitions.. While previous literature investigated training speed of isotonic exercises and effects on strength (Keeler et al., 2001; Munn et al., 2005; Neils et al., 2005; Rana et al., 2008; Tanimoto & Ishii, 2006; Westcott et al., 2001), less literature is focused on acute effects of repetition speed on power and repetitions (Sakamoto & Sinclair, 2006; Hatfield et al., 2006). Only one previous study examined the effects of interrepetition rest on concentric power (Lawton et al., 2006), and they used very long and impractical rest intervals for resistance training. No previous studies have focused on the effect of repetition tempo, which incorporates both speed of movement and rest intervals, on concentric power output during resistance training. In this chapter the results are discussed in subsections: (1) Repetitions, (2) Power, and (3) Implications for Resistance Training.

Repetitions

It is well documented that resistance training with a heavy load is beneficial to both strength and power gains (Keeler et al., 2001; Munn et al., 2005; Neils et al., 2005; Rana et al., 2008; Tanimoto & Ishii, 2006; Vikne et al., 2006; Westcott et al., 2001). By increasing the number of repetitions in a set, the volume of work also increases which is expected to elicit greater strength and power gains over the course of a training program. In the current study, tempos A, B, and F, each containing three seconds of interrepetition rest produced similar repetitions as their continuous lifting counterparts, C, D, E, respectively. Therefore, rest intervals of 3 s between repetitions did not affect the number of repetitions performed in a single set of exercise. This contradicts the hypothesis that interrepetition rest elicits greater repetitions by allowing time for muscle recovery through the removal of metabolic end products and replenishment of phosphocreatine in the muscle (Byrd et al., 1988; Lawton et al., 2006). Studies using greater rest with racking the weights between repetitions demonstrated the potential for interrepetition rest to increase power (Lawton et al.) and volume of work (Byrd et al.). This suggests that 3 s rest while holding the weights between repetitions is not sufficient to allow for muscle recovery. However, the protocol used in the present study is more practical than interrepetition rest of 23 to 118 s used by Lawton et al.. Perhaps 3 s interrepetition rest would impact performance if subjects used multiple sets of bench press as commonly done during a resistance exercise session. In summary, a 3 s interrepetition rest interval without racking the weight is practical but was not found to be effective in the present study.

Tempos with short eccentric phases and no bottom rest (A and C) produced greater repetitions than tempos with 4 s eccentric phases (E and F) or 3 s bottom rest intervals (B and D). Previous research supporting these results indicated fast eccentric phases increase the number of successful repetitions and utilize the stretch shortening cycle (SSC), which is a pre-stretch of the muscle that produces a stronger reflex contraction than a concentric contraction alone. Augmented concentric contraction is attributed to the storage and reutilization of elastic energy of the series elastic component of the musculo-tendinous system (Cronin et al., 2001). This increase in the rate of concentric contraction is observed especially in the initial phase of the contraction where peak power is produced (Cronin et al.). Hatfield et al. (2006) found faster eccentric speeds of a self-selected pace produced greater repetitions as compared to a 10 s eccentric phase. Sakamoto & Sinclair (2006) also studied varying eccentric speeds and concluded 1 s and maximal speed eccentric phases resulted in higher repetitions than eccentric speeds of 2.8 s and 1.4 s. It seems reasonable to speculate a slow eccentric phase or long bottom rest each inhibit the SSC and reduce the number of repetitions performed in a single set of exercise.

Tempos with longer eccentric phases (E and F) also had fewer repetitions than A and C which may be due to greater eccentric time under tension (TUT) which refers to the total time a muscle performs work (Hatfield et al., 2006). Greater eccentric TUT (i.e. tempos E and F) may cause a fatiguing effect thereby lessening repetition number compared to a set with little eccentric TUT (i.e., A and C). Eccentric TUT may be important to positive long-term resistance training adaptations such as strength (Neils et al., 2005; Tanimoto & Ishii, 2006; Westcott et al., 2001), power (Morrissey et al., 1998), and muscle fiber cross sectional area (Shepstone et al., 2006; Tanimoto & Ishii), but the present study did not examine chronic training effects.

In addition to increased power output, an increase in the number of repetitions is important for many strength tests in professional sports such as done at the National Football League (NFL) Scouting Combine. The Combine requires athletes to lift a predetermined weight (225 lbs) until failure and measures successful repetitions to compare athletes who play similar positions. As seen in this study, lifting with a tempo of faster eccentric speed and no pause between eccentric and concentric phases should result in performing a greater number of repetitions and the most successful outcome.

Power

Peak power output describes the highest concentric power output in a repetition. The current study found significantly greater peak power output with tempos consisting of fast eccentric speeds and no bottom rest (i.e., A and C). Interrepetition rest did not have a significant effect on peak power output. Additionally, over the course of a set, fast eccentric tempos without rest had significantly greater average peak power than other tempos. In practical terms, greater peak power was produced in a single repetition and maintained throughout all repetitions of the entire set when eccentric velocity was greatest and no bottom rest allowed. The combination of a greater number of repetitions and a higher peak concentric power in these tempos (i.e., A and C), indicates that a greater total work volume was accomplished in tempos with rapid eccentric contractions and no bottom rest.

A previous investigation by Hatfield et al. (2006) supports these results although the methodology differed. Performing movements at faster eccentric speeds was found to increase peak power output, however, subjects lifted either to a cadence of 10 s eccentric and concentric phases, or a faster self-selected pace. Lower concentric power of the slower cadence was likely due to the drastic difference in concentric speed and not necessarily a difference in eccentric speed. Power (force multiplied by velocity) was expected to be lower simply due to the slower velocity with equal force. Had the concentric lifting speed been maximal, these results might directly support the current findings.

In the present study, maximum mean power was significantly greater with tempos utilizing the SSC (i.e., fast eccentric speeds and no bottom rest such as tempos A and C).

Not only was mean power greater for the first repetition, but it was also greater throughout the course of the set (average mean power) for tempos with fast eccentric velocity and no bottom rest (i.e., tempos A & C). These results were reported by Cronin et al. (2001), by finding higher maximum mean power during repetitions with an eccentric phase preceding a concentric phase as compared to bench press with only concentric phase repetitions. The higher maximum mean power due to the SSC suggests greater contraction power occurs due to a pre-stretch of the muscle.

Interrepetition rest had no significant effect on maximum mean power in the present study. Lawton et al. (2006) found higher maximum mean power with interrepetition rest intervals of 23, 56, and 109 s as compared to continuous lifting. Although maximum mean power was greater, these intervals, for which the bar was re-racked, are not practical for resistance training. Interrepetition rest greater than 3 s but less than 23 s may also be effective, however, these interrepetition rest intervals were not presently studied. Future studies should attempt to determine the minimum interrepetition rest needed to increase concentric power throughout a set of exercise. Future studies should also investigate the effect of interrepetition rest on power using a lower intensity mimicking endurance weight training (i.e., lower weight and higher repetitions). In summary, it was hypothesized that an increase in interrepetition rest would also increase power output due to a longer recovery period for the muscle but this was not found to be true. Perhaps if the bar was re-racked during interrepetition rest an increase in power would be observed.

Implications for Resistance Training

The most effective training tempo for enhancing resistance exercise adaptation is still unknown. Although this study found shorter eccentric phases and no bottom rest (i.e., tempos A and C) created the greatest number of repetitions and power outputs, these tempos may not be the most beneficial for chronic strength training. Training with long eccentric phases leads to muscle hypertrophy (Farthing & Chilibeck, 2003; Vikne et al., 2006) and improvements in strength and power (Morrissey et al., 1998; Neils et al., 2005; Westcott et al., 2001). Training with eccentric contractions preceding concentric contractions utilizes the SSC and increases power as well (Cronin et al., 2001). It is unknown, however, if interrepetition rest intervals are beneficial to strength or power gains over the course of a training program. In other words, although fast eccentric contractions with no bottom rest yield greater total concentric work, a training study using the six tempos might yield different results for long-term strength gain. Other variables such as eccentric TUT or peak eccentric power may be critical to long term gains and must also be considered.

Byrd et al. (1988) studied the effects of a 10-week strength training program on work output during upper body ergometry and concluded 1 and 2 s interrepetition rest intervals increased work output greater than continuous lifting. Since the exercise program was performed with machine weights and testing was performed on an ergometer, comparison of results to the present study is difficult due to the training and testing mode differences. Work was greater for tempos with fast eccentric and no bottom rest phases due to a greater number of repetitions. Since more work was performed with these tempos (i.e., A and C), greater strength may possibly develop if used throughout a training program. Future research should determine if this greater work volume as seen in previous research (Byrd et al.) can also be performed at fast speeds to develop greater power.

Although it has not yet been investigated, having interrepetition rest during each set may improve power over the course of subsequent sets, therefore increasing power production during each training session. Therefore, resistance training with interrepetition rest could increase strength and power more than continuous lifting tempos. Future training studies should address the lack of research involving the effect of tempos with varying interrepetition rest for multiple sets throughout a resistance training program. Research is also needed to investigate the effects of the SSC with lower intensities as seen with muscular endurance training.

The single most applicable practical finding for the current study is related to acute performance testing. If maximal concentric power output or repetitions in a single set is the goal, then maximizing eccentric velocity and minimizing bottom rest should improve performance. Tests such as the YMCA bench press test, the NFL combine bench press, and possibly even tests of muscular endurance (e.g., sit-ups and push-ups) can benefit from the previously mentioned tempo.

Summary

Given the boundaries of the present study, weight lifting with tempos combining fast eccentric phases and no bottom rest interval should be most beneficial to acute performance as seen during athletic testing. Power and repetition number were both highest when fast eccentric phases and no bottom rest were used. During a set and within a repetition, the SSC appears important to performance. Interrepetition rest of 3 s did not enhance performance in the current study, but longer intervals should be examined in future research. Although chronic resistance training with these tempos was not studied in the current investigation, varying repetition tempo and interrepetition rest should be studied over the course of a training program.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMEDNATIONS

Summary

This study examined the effects of bench press tempo on concentric power and number of repetitions. Male (N = 24), resistance trained Ithaca College students volunteered to participate in this study. Subjects completed 1RM testing and returned six additional days, each day completing one set of bench press at 80% 1RM to the cadence of a metronome. Each tempo consisted of a specific eccentric speed, bottom rest interval, and interrepetition rest, while concentric speed was always maximal. Trial order was counterbalanced and trials were at least 48 h apart. A five min warm-up on a cycle ergometer and three bench press repetitions at 50% 1RM to the cadence of a metronome were completed prior to testing. Subjects were instructed to maintain the cadence as closely as possible. Tempo repetitions were then completed until failure.

Power was calculated from kinematic data obtained with a reflective marker placed on the end of the Olympic bar and tracked through video analysis. Number of repetitions, peak power output, average peak power, maximum mean power, and average mean power were calculated and statistically analyzed with a repeated measures one-way ANOVA for each dependent variable. Tempos with fast eccentric speed and no bottom rest interval were statistically greater than other tempos for all dependent variables. Interrepetition rest had no significant effect on any dependent variable.

Conclusions

Results of this study support the following conclusions:

1. Bench press repetition tempos with short eccentric phases and no bottom rest produce the greatest repetition number, peak power output, average peak power, maximum mean power, and average mean power.
2. Introducing bottom rest or a longer eccentric phase into a bench press set hampers concentric performance.
3. Three seconds of interrepetition rest does not affect any of the dependent variables.
4. Acute testing performance should benefit from short eccentric phases and no bottom rest, however, this study can make no conclusions regarding the best repetition tempo for a long-term training program.

Recommendations

The following recommendations for future study are to examine the effects of:

1. Interrepetition rest intervals greater than 3 s and less than 23 s on power and number of repetitions.
2. Varying repetition tempos at a lower intensity to mimic endurance resistance training.
3. Varying repetition tempos over the course of chronic resistance training.
4. Using short interrepetition rest intervals (e.g., 3-5 s) during multiple sets in a resistance exercise session.

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APPENDIX A

Medical History Form

Name ________________________________ Age ________

Medical Health History (please circle any that apply)

Heart Disease Irregular Heart Rhythms

High Blood Pressure Musculoskeletal Injury

Present Symptoms (please circle any that have applied **within the past 6 months**)

Chest Pain Shortness of Breath Heart Palpitations

Loss of Consciousness Surgery/Hospitalization Musculoskeletal Injury

Lightheadedness Other:

____

Medications (Please list all medications presently being taken)

Exercise Habits

Do you presently engage in resistance training? Yes No

How many times per week do you resistance train? _______________

For how long do you resistance train each session? _______________

How many months/years have you resistance trained? __________________

APPENDIX B

Informed Consent

Optimizing Power Output by Varying Repetition Tempo

1. **Purpose of the Study:** The purpose of this study is to investigate how varying interrepetition rest and repetition velocity affect power output and the number of repetitions performed during a set of resistance exercise. The goal is to develop effective recommendations for repetition tempo.

2. **Benefits:** You may benefit from participating in this study because you will learn what your maximal strength is for bench press and get an understanding of repetition tempo. You will also get first hand experience on how scientific data are collected. Your participation will also benefit the researcher, who is working on her thesis. Last, it is hoped that the data generated will benefit the scientific community and exercise professionals.

3. **Your Participation** requires you to be between 18 and 25 years old and able to complete seven maximum bench press strength and power tests. All sessions will be performed in the Exercise Physiology Laboratory in CHS 303. You will be asked to complete a Health and 24 Hour History. In the project's first session, you will complete a one repetition maximum (1 RM) of the bench press. This requires you exert maximal effort at a maximal resistance. Prior to the 1 RM, you will warm-up by pedaling for five minutes against a light resistance. Total time for this session is about 20 min.

In sessions 2-7, you will perform one set of the bench press at 80% of your 1 RM determined during the first session. Each day will consist of a different tempo (the timing which you move the bar) that you will become familiar with on that day. The total time of each tempo session is approximately 10 min. Between testing sessions, 48 hours will be given.

Total participation time for the entire study is about 1 hr, 20 min over the course of three weeks.

4. **Risks of Participation:** The risks associated with strength and power testing include skeletal muscle injury, fatigue, and soreness. If you become sore, this should dissipate 24 to 48 hours after the exercise. To minimize risks, you will warm-up before each session. If you feel poorly at any time, you may terminate the session. There will be at least one researcher certified in CPR and First Aid at all testing sessions. These technicians will promptly provide standard first aid procedures in the event that you are injured.

APPENDIX B (continued)

5. Compensation for Injury: If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost of such care is your responsibility. If you have insurance, you may bill your insurance company. Ithaca College and the investigator will not pay for any care, lost wages, or provide other compensation.

6. If you would like more information about this study at any time prior to, during, or following the data collection, you may contact Riana Czapla at rczapla1@ithaca.edu or 716.348.9306. You may also contact Dr. Gary Sforzo (sforzo@ithaca.edu) (274.3359)

7. Withdrawal from the study: Participation in this study is voluntary and you may withdraw at any time.

8. Confidentiality: Information gathered during this study will be maintained in complete confidence. Only the researchers will have access to this information, which will be stored in a locked cabinet in room 312 in the Center for Health Sciences at Ithaca College or on a password protected computer. You or your name will never be associated with this information in any future papers, publications, presentations, etc. To further insure confidentiality, all files will be number coded and data collection instruments will be kept separately from Informed Consent Forms and sign-up sheets.

I have read and understood the above document. I agree to participate in this study and realize that I can withdraw at anytime. I also understand that I can and should address questions related to this study at any time to any of the researchers involved. I also verify that I am at least 18 years of age.

____

Your Name (please print)

____

Your Signature   Date

APPENDIX C

24 Hour History

Name______________________________ Date____________________

ID #______________________________

Present Health Status (please circle all that apply)

Body Ache Sore Throat Dizziness Chest Pain Nausea Feel Fine

Diet

Have you consumed alcohol in the last 12 hours?	Yes	No
Have you used caffeine or nicotine in the last 3 hours?	Yes	No

Exercise

Have you performed heavy upper body exercise in the past 24 hours?	Yes	No
Has there been a change in your exercise program since the last testing session?	Yes	No

Over the Counter / Prescription Drugs

Have you taken any over the counter drugs in the last 24 hours?	Yes	No
Have there been changes in any of your current prescription drugs since the last session?	Yes	No

Injury

Have you experienced any injuries since the last testing session?	Yes	No
Have there been any other changes since the last testing session that may compromise your performance on today's testing?	Yes	No

APPENDIX D

Raw Data Key

Abbreviation	Definition
Reps A	Number of repetitions for Tempo A
AvgMeanPA	Average mean power for Tempo A
AvgPeakPA	Average peak power for Tempo A
PeakPeakPA	Peak of the peak powers for Tempo A
PeakMeanPA	Peak of the mean powers for Tempo A
EccTimeA	Time to complete the eccentric phase for Tempo A
BottomTimeA	Time to complete the bottom rest for Tempo A
ConcTimeA	Time to complete the concentric phase for Tempo A
TopTimeA	Time to complete the interrepetition rest for Tempo A
RepsB	Number of repetitions for Tempo B
AvgMeanPB	Average mean power for Tempo B
AvgPeakPB	Average peak power for Tempo B
PeakPeakPB	Peak of the peak powers for Tempo B
PeakMeanPB	Peak of the mean powers for Tempo B
EccTimeB	Time to complete the eccentric phase for Tempo B
BottomTimeB	Time to complete the bottom rest for Tempo B
ConcTimeB	Time to complete the concentric phase for Tempo B
TopTimeB	Time to complete the interrepetition rest for Tempo B
RepsC	Number of repetitions for Tempo C
AvgMeanPC	Average mean power for Tempo C
AvgPeakPC	Average peak power for Tempo C
PeakPeakPC	Peak of the peak powers for Tempo C
PeakMeanPC	Peak of the mean powers for Tempo C
EccTimeC	Time to complete the eccentric phase for Tempo C
BottomTimeC	Time to complete the bottom rest for Tempo C
ConcTimeC	Time to complete the concentric phase for Tempo C

APPENDIX D (Continued)

Abbreviation	Definition
TopTimeC	Time to complete the interrepetition rest for Tempo C
RepsD	Number of repetitions for Tempo D
AvgMeanPD	Average mean power for Tempo D
AvgPeakPD	Average peak power for Tempo D
PeakPeakPD	Peak of the peak powers for Tempo D
PeakMeanPD	Peak of the mean powers for Tempo D
EccTimeD	Time to complete the eccentric phase for Tempo D
BottomTimeD	Time to complete the bottom rest for Tempo D
ConcTimeD	Time to complete the concentric phase for Tempo D
TopTimeD	Time to complete the interrepetition rest for Tempo D
RepsE	Number of repetitions for Tempo E
AvgMeanPE	Average mean power for Tempo E
AvgPeakPE	Average peak power for Tempo E
PeakPeakPE	Peak of the peak powers for Tempo E
PeakMeanPE	Peak of the mean powers for Tempo E
EccTimeE	Time to complete the eccentric phase for Tempo E
BottomTimeE	Time to complete the bottom rest for Tempo E
ConcTimeE	Time to complete the concentric phase for Tempo E
TopTimeE	Time to complete the interrepetition rest for Tempo E
RepsF	Number of repetitions for Tempo F
AvgMeanPF	Average mean power for Tempo F
AvgPeakPF	Average peak power for Tempo F
PeakPeakPF	Peak of the peak powers for Tempo F
PeakMeanPF	Peak of the mean powers for Tempo F
EccTimeF	Time to complete the eccentric phase for Tempo F
BottomTimeF	Time to complete the bottom rest for Tempo F
ConcTimeF	Time to complete the concentric phase for Tempo F
TopTimeF	Time to complete the interrepetition rest for Tempo F

APPENDIX E

Raw Data

Subject	RepsA	AvgMeanPA	AvgPeakPA	PeakPeakPA	PeakMeanPA	EccTimeA	BottomTimeA	ConcTimeA	TopTimeA
1	10	167.37	290.42	400.59	268.55	1.207	0.035	1.733	2.591
2	8	203.66	395.02	476.96	267.29	0.698	0.019	1.156	3.326
3	8	291.05	410.30	492.93	366.92	1.190	0.031	1.067	2.714
4	8	350.39	624.15	695.09	452.58	0.833	0.025	1.027	3.095
5	6	330.13	539.47	573.07	404.27	1.419	0.061	1.256	2.473
6	6	245.56	403.04	500.26	326.67	0.967	0.206	1.164	2.710
7	7	310.53	620.46	714.05	401.88	1.138	0.024	1.414	3.200
8	7	326.09	505.77	591.37	456.30	1.193	0.029	1.405	2.839
9	9	283.12	502.87	644.35	363.92	1.378	0.054	1.287	2.600
10	9	201.11	324.95	408.32	278.45	1.069	0.046	1.478	2.717
11	10	186.22	309.73	407.14	291.58	1.143	0.023	1.403	2.813
12	9	244.56	359.92	514.93	381.59	1.363	0.174	1.307	2.504
13	6	238.51	344.09	388.79	302.66	0.919	0.036	1.342	2.797
14	7	179.68	300.71	332.87	227.09	0.938	0.038	1.481	2.639
15	16	198.40	311.71	457.51	290.13	0.958	0.051	1.327	2.899
16	8	285.38	451.98	547.69	371.92	0.737	0.196	1.312	3.157
17	10	213.26	335.60	398.99	277.80	1.235	0.038	1.415	2.844
18	7	245.30	411.21	487.31	338.32	1.224	0.040	1.545	2.442
19	8	173.30	250.58	313.20	210.73	1.215	0.450	1.296	2.457
20	12	305.23	441.59	570.98	394.02	0.799	0.051	1.233	2.921
21	9	226.26	344.35	410.92	271.16	1.080	0.041	1.126	2.677
22	12	232.15	360.98	466.96	320.89	1.114	0.028	1.347	2.862
23	6	302.92	468.22	502.38	387.67	0.711	0.039	1.131	2.557
24	6	338.08	750.38	792.60	424.72	0.953	0.017	1.189	2.773

APPENDIX E (Continued)

Subject	RepsB	AvgMeanPB	PeakMeanPB	AvgPeakPB	PeakPeakPB	EccTimeB	BottomTimeB	ConcTimeB	TopTimeB
1	4	152.71	214.44	254.05	298.39	1.392	2.467	1.521	3.222
2	4	161.57	193.81	307.48	346.79	1.383	2.596	1.608	2.433
3	4	239.00	275.03	337.70	404.56	1.312	2.642	1.350	2.806
4	7	288.85	356.20	455.20	495.47	1.157	2.729	1.488	3.108
5	5	242.97	357.33	457.49	549.61	1.200	2.967	2.143	2.533
6	2	173.23	179.21	309.36	315.81	1.100	5.017	1.317	2.517
7	6	217.88	331.79	363.16	433.94	1.119	2.939	1.994	2.327
8	5	272.35	324.82	430.75	479.89	1.763	2.593	1.827	2.896
9	5	250.18	361.56	493.75	664.22	1.570	2.350	1.617	3.133
10	4	174.76	195.97	271.21	328.59	1.312	2.875	1.471	3.450
11	5	157.28	220.03	301.07	388.08	1.237	2.767	1.707	2.679
12	5	146.88	216.28	275.28	333.96	2.057	1.720	2.417	2.554
13	4	199.23	240.98	273.46	313.32	0.892	2.612	1.762	2.767
14	5	174.44	214.50	315.53	391.88	1.290	2.603	1.613	2.871
15	5	166.75	217.16	317.43	426.37	0.960	2.587	1.673	3.112
16	6	246.37	319.05	430.89	496.84	1.356	2.506	1.569	2.680
17	6	198.40	242.50	316.15	368.70	1.964	1.828	1.703	3.003
18	5	218.21	297.43	319.39	454.73	1.250	2.547	1.693	2.746
19	5	218.21	297.43	319.39	454.73	1.170	2.453	1.773	2.829
20	7	194.73	260.04	352.36	460.59	1.112	2.593	1.843	3.458
21	2	184.43	184.73	322.40	325.39	1.358	2.083	1.475	2.850
22	8	178.48	278.18	271.62	401.39	1.640	2.269	1.896	2.717
23	3	207.60	240.93	359.31	445.04	0.872	2.944	1.544	3.050
24	4	282.46	349.42	441.15	515.73	1.000	2.992	1.558	2.867

APPENDIX E (Continued)

Subject	RepsC	AvgMeanPC	PeakMeanPC	AvgPeakPC	PeakPeakPC	EccTimeC	BottomTimeC	ConcTimeC	TopTimeC
1	10	233.30	315.57	351.75	505.87	1.057	0.037	1.393	0.320
2	8	166.74	255.02	303.54	374.83	1.054	0.029	1.294	0.448
3	10	301.11	390.10	456.15	582.78	1.137	0.017	1.155	0.217
4	10	357.08	481.82	606.56	672.02	0.973	0.028	1.162	0.174
5	6	268.54	375.03	397.41	539.94	1.114	0.253	1.242	0.207
6	7	218.99	289.69	376.47	486.24	1.057	0.133	1.364	0.369
7	8	287.46	423.75	554.98	616.34	0.985	0.033	1.467	0.033
8	9	323.90	395.15	551.00	602.35	1.041	0.026	1.465	0.625
9	10	286.48	417.33	537.70	722.70	1.183	0.043	1.453	0.122
10	9	195.18	282.18	268.18	372.59	0.985	0.046	1.265	0.069
11	13	175.23	264.15	294.22	391.64	0.872	0.031	1.568	0.175
12	11	290.77	392.01	442.94	572.33	0.995	0.029	1.209	0.258
13	8	254.87	314.35	373.92	465.96	0.898	0.029	1.325	0.338
14	12	218.91	309.27	356.07	470.83	0.946	0.056	1.181	0.105
15	13	226.06	310.92	346.84	555.16	1.086	0.065	1.209	0.118
16	7	253.18	349.40	412.55	454.41	0.883	0.038	1.655	0.047
17	6	219.41	278.96	346.65	390.20	1.122	0.039	1.353	0.033
18	9	216.81	355.37	374.10	467.36	0.998	0.039	1.606	0.125
19	10	190.39	236.26	284.33	356.65	0.890	0.035	1.208	0.143
20	13	309.53	445.87	471.37	681.75	0.854	0.028	1.199	0.293
21	7	223.16	245.53	365.94	418.21	0.979	0.038	1.179	0.056
22	13	210.65	340.70	351.32	523.08	0.721	0.033	1.413	0.208
23	7	262.89	332.42	468.00	546.84	0.705	0.029	1.205	0.261
24	7	326.51	466.80	690.55	754.73	0.831	0.019	1.410	0.931

APPENDIX E (Continued)

Subject	RepsD	AvgMeanPD	PeakMeanPD	AvgPeakPD	PeakPeakPD	EccTimeD	BottomTimeD	ConcTimeD	TopTimeD
1	4	147.75	180.62	262.03	297.43	1.408	2.421	1.996	0.061
2	5	182.51	246.19	331.95	400.22	0.873	3.130	1.283	0.154
3	3	248.00	294.86	366.76	421.59	1.461	2.294	1.233	0.042
4	7	284.34	380.21	435.38	522.91	1.371	2.660	1.471	0.158
5	4	245.31	326.99	409.55	474.20	1.192	2.479	1.483	0.283
6	4	162.09	246.44	336.43	452.02	1.075	2.638	2.504	0.239
7	7	216.80	330.71	379.53	469.31	1.148	2.605	2.048	0.042
8	6	310.79	364.76	485.04	579.32	1.253	2.133	1.481	0.263
9	5	243.91	308.78	471.56	579.37	1.320	2.077	1.673	0.450
10	5	184.89	209.57	262.77	303.32	1.417	2.380	1.520	0.179
11	4	152.57	197.31	290.60	368.14	1.283	2.437	1.671	0.161
12	5	278.50	341.43	430.93	547.73	1.390	2.150	1.337	0.175
13	4	215.44	245.74	294.31	328.90	1.096	2.392	1.525	0.228
14	5	167.29	233.69	320.56	369.54	1.430	2.100	1.603	0.092
15	8	165.22	227.03	341.81	424.24	1.317	2.002	1.679	0.376
16	3	245.72	309.08	343.37	380.05	1.089	2.883	1.517	0.067
17	6	213.86	258.02	369.31	456.56	1.483	2.319	1.478	0.030
18	6	169.91	227.57	267.31	333.25	1.797	2.244	2.561	0.117
19	4	152.15	185.72	206.21	259.49	1.054	2.212	1.650	0.778
20	6	236.02	290.61	414.96	505.91	0.986	2.961	1.531	0.140
21	4	194.47	237.03	315.63	334.06	1.475	1.992	1.392	0.033
22	7	203.29	290.10	338.66	435.61	1.038	2.576	1.579	0.133
23	4	226.30	287.10	416.85	476.91	1.142	2.471	1.650	0.056
24	5	281.04	362.40	429.59	478.79	1.087	2.497	1.563	0.037

APPENDIX E (Continued)

Subject	RepsE	AvgMeanPE	PeakMeanPE	AvgPeakPE	PeakPeakPE	EccTimeE	BottomTimeE	ConcTimeE	TopTimeE
1	5	204.17	254.89	390.82	424.35	3.783	0.077	1.793	0.221
2	4	148.56	178.41	252.83	289.19	3.988	0.096	1.504	0.089
3	5	275.04	318.23	379.29	447.36	3.623	0.077	1.123	0.192
4	6	294.68	381.01	491.42	543.49	3.567	0.047	1.425	0.330
5	4	227.18	310.96	433.68	526.25	3.371	0.042	1.717	0.056
6	2	211.65	241.17	362.30	398.90	2.092	1.450	1.433	0.083
7	6	232.24	346.47	422.20	509.48	3.619	0.058	1.761	0.067
8	6	237.55	328.57	435.87	566.92	3.450	0.083	2.258	0.367
9	6	245.45	303.13	407.17	495.97	3.464	0.078	1.656	0.050
10	6	183.39	257.22	282.33	346.61	3.633	0.061	1.789	0.180
11	5	207.38	247.20	340.68	432.17	3.813	0.043	1.210	0.054
12	5	226.62	292.48	349.86	425.32	3.663	0.050	1.427	0.037
13	5	188.90	226.03	272.12	312.77	3.523	0.063	1.887	0.071
14	5	165.74	230.14	320.56	369.54	1.600	1.983	1.610	0.062
15	9	194.60	246.89	310.83	408.44	3.572	0.089	1.417	0.106
16	5	215.45	303.87	318.01	431.53	3.167	0.210	1.780	0.388
17	6	180.26	248.31	267.96	315.81	3.650	0.081	1.789	0.043
18	5	166.69	242.22	291.57	333.65	3.720	0.070	1.977	0.092
19	6	171.62	245.08	248.54	324.20	3.642	0.061	1.519	0.113
20	9	233.31	336.24	386.90	501.17	3.724	0.107	1.600	0.100
21	5	184.34	250.38	309.91	429.96	3.537	0.083	1.427	0.037
22	7	182.92	263.27	272.59	367.84	3.662	0.119	1.748	0.078
23	4	232.91	275.28	364.81	508.65	3.558	0.046	1.346	0.050
24	6	225.14	336.96	443.68	492.04	3.439	0.061	2.003	0.063

APPENDIX E (Continued)

Subject	RepsF	AvgMeanPF	PeakMeanPF	AvgPeakPF	PeakPeakPF	EccTimeF	BottomTimeF	ConcTimeF	TopTimeF
1	6	117.39	169.58	247.50	326.64	3.681	0.083	2.436	2.843
2	4	146.71	189.62	240.75	264.00	3.879	0.079	1.321	3.289
3	6	278.93	346.70	405.64	580.44	3.272	0.047	1.189	2.960
4	5	252.79	335.71	458.03	500.97	3.793	0.150	1.567	3.158
5	3	263.54	309.02	413.79	451.46	3.550	0.450	1.433	2.625
6	3	243.42	282.84	356.90	390.80	3.511	0.056	1.217	3.317
7	3	241.19	294.02	425.04	456.95	3.922	0.056	1.494	2.642
8	5	301.50	337.20	461.96	527.26	3.520	0.163	1.420	2.975
9	5	185.40	250.62	361.94	509.06	3.827	0.090	2.393	2.775
10	5	190.13	257.99	293.75	377.31	3.887	0.057	1.617	2.521
11	5	155.54	188.89	252.94	330.75	3.910	0.183	1.567	2.538
12	6	190.40	259.87	320.61	390.74	3.781	0.039	1.983	2.547
13	4	188.04	258.44	261.25	332.53	3.517	0.067	1.738	2.706
14	6	156.48	204.46	289.21	344.43	3.425	0.103	1.758	3.013
15	9	165.04	220.16	253.94	393.42	3.169	0.102	1.663	3.258
16	5	194.18	247.00	321.75	352.70	4.343	0.107	2.053	2.388
17	6	190.30	243.56	299.09	354.33	3.997	0.075	1.461	2.883
18	5	160.96	255.61	283.27	351.65	3.987	0.100	2.523	2.783
19	5	141.55	196.01	209.84	266.24	3.457	0.083	1.733	2.883
20	6	260.40	302.83	421.31	470.69	3.425	0.050	1.356	3.197
21	5	224.59	307.40	327.38	411.55	3.553	0.027	1.223	2.408
22	7	179.23	221.02	297.24	343.41	3.912	0.060	1.745	2.792
23	3	194.85	222.36	299.51	341.16	3.517	0.044	1.467	2.967
24	3	234.58	276.30	448.99	497.28	3.556	0.056	1.906	2.800

Note. All power data is W. All time data is sec.