This is a non-final version of an article published in final form in Journal of Strength and Conditioning Research, Volume 25, Number 11, pp. 3163-3174.

Full Title: Kinematic and kinetic analysis of maximal velocity deadlifts performed with and without the inclusion of chain resistance

Short Title: Explosive resistance training with variable- and non-variable loads

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ABSTRACT.

The purpose of this study was to investigate whether the deadlift could be effectively incorporated with explosive resistance training (ERT), and to investigate whether the inclusion of chains enhanced the suitability of the deadlift for ERT. Twenty three resistance trained athletes performed the deadlift with 30, 50 and 70% 1RM loads at submaximal velocity, maximal velocity, and maximal velocity with the inclusion of two chain loads equal to 20 or 40% of the subjects 1RM. All trials were performed on force platforms with markers attached to the barbell to calculate velocity and acceleration using a motion capture system. Significant increases in force, velocity, power, rate of force development and length of the acceleration phase ($p < 0.05$) were obtained when repetition velocity increased from submaximal to maximal. During maximal velocity repetitions with a constant resistance the mean length of the acceleration phase ranged from 73.2 (± 7.2%) to 84.9 (± 12.2%) of the overall movement. Compared to using a constant resistance the inclusion of chains enabled greater force to be maintained to the end of the concentric action and significantly increased peak force and impulse ($p < 0.05$), whilst concurrently decreasing velocity, power and rate of force development ($p < 0.05$). The effects of chains were influenced by the magnitude of the chain and barbell resistance, with greater increases and decreases in mechanical variables obtained when heavier chain and barbell loads were used. The results of the investigation suggest that the deadlift can be incorporated effectively in ERT programs. Coaches and athletes should be aware that the inclusion of heavy chains may have both positive and negative effects on kinematics and kinetics of an exercise.

Key Words: variable resistance, power, force, speed

INTRODUCTION

Performing resistance training with the intention to lift the load as fast as possible is a common training method used among athletic populations. The practice is commonly referred to as explosive resistance training (ERT) and is currently recommended to improve muscular power and athletic performance (1, 39). Theoretically, ERT provides an effective training method as both the intent to lift a load as fast as possible and rapid movement velocity have been shown to be important stimuli that elicit high-velocity-specific neuromuscular adaptations (23). Exercise selection is considered to be an important acute program variable for ERT and the development of muscular power (1). Two broad categories of resistance exercises (referred to as traditional and ballistic) are frequently incorporated with ERT (1, 31, 32). However, some researchers have cautioned against performing traditional resistance exercises explosively due to suggestions that the exercises are limited by periods of deceleration and reduced force production during the latter stages of the concentric action (24, 32). Instead, it is generally recommend that ERT is performed with exercises such as the jump squat, bench throw, and power clean which are considered to be representative of ballistic exercises that enable force and acceleration to be maintained throughout the concentric action (24, 32). During the jump squat and bench throw, athletes are able to maintain force and acceleration by projecting the load at the end of the movement. In a similar manner it is argued that during the power clean the barbell is effectively projected at the end of the extension phase and begins to decelerate under the action of gravity as the lifter drops into the catch position (22). Previous suggestions that traditional resistance training exercises are unsuitable for ERT are based predominantly on results from a limited number of studies. In addition, research demonstrating periods of deceleration and reduced force production during traditional resistance exercises has been restricted to the bench press (16, 26, 32). Other traditional resistance exercises that involve movement at a greater number of joints may provide more complex control strategies that enable force and acceleration to be maintained for greater portions of the movement. The deadlift was chosen for the present study as it involves motion at all major joints of the lower body and despite traditionally being viewed as an exercise solely for strength development, recent evidence shows that athletes are currently using the exercise for the purposes of developing muscular power (9, 40).

More recently, attempts have been made to enhance the stimulus of traditional resistance exercises used with ERT by including resistance in the form of chains (28). This training practice is commonly referred to as variable resistance training and requires chains to be placed on the floor and attached symmetrically to the ends of the barbell. Total resistance varies throughout the exercise depending on the height of the barbell and subsequent mass of chains unfurled from the floor. It has been suggested that the addition of chains alters the mechanics of traditional resistance exercises to make them more suitable for ERT (4, 38). This suggestion is based on the theory that increasing resistance from unfurling chain mass will require the lifter to maintain force production to elevate the barbell to its final position (5, 7, 8, 15). To date, there have been no published reports that have directly examined this theory. Only a limited number of studies have investigated the effects of including chains on the biomechanics of resistance exercises (5, 7, 8, 15). Ebben and Jensen (15) reported that the inclusion of chain resistance had no effect on lift kinetics or EMG activity during the back squat. Coker and colleagues also failed to report any effects of chains on the kinematics and kinetics of the snatch (8) and clean (7). In contrast, Baker and

Newton (5) reported that the inclusion of chains significantly increased mean and peak lifting velocities during the bench press. Conflicting results may be explained by the different magnitudes of chain resistance used. In each of the previous studies repetitions performed with a constant barbell load were compared with repetitions where a portion of the barbell mass was substituted for an equivalent mass of chains. Studies reporting no significant differences between conditions substituted 6 to 10% of the barbell mass with chains (7, 8, 15), whereas, Baker and Newton (5) obtained significant increases in lifting velocity when substituting on average 25% of the barbell mass. The contrasting results suggest that a minimum amount of chain mass may be required to alter exercise kinematics and kinetics. Based on their own findings and results from studies investigating a similar training practice where rubber bands were used instead of chains, Baker and Newton (5) recommended that chain masses greater than 15% of a lifters maximum strength (1RM) should be used when attempting to alter the mechanical stimulus of an exercise.

An important aspect of resistance training with chains that has not been investigated in sufficient depth is the interaction effect of different chain and barbell loads. Only two studies that have investigated the effects of chain resistance have used more than one barbell load in their experimental protocol (7, 8). In both studies the barbell loads differed by 5% 1RM (75 vs. 80% 1RM). In contrast, research has identified that athletes perform a variety of exercises explosively with loads ranging from 40 to 100% 1RM (40). In addition, no studies have compared the effects of different chain loads with the same population. In order to effectively prescribe the use of chains within a resistance training program knowledge of the interaction of different chain and barbell loads will be required.

The present study had three main purposes: firstly, to investigate the suitability of the deadlift for ERT; secondly, to investigate whether the inclusion of chains improved the suitability of the deadlift for ERT; and thirdly, to investigate the interaction effects of different chain and barbell loads on exercise kinematics and kinetics.

METHODS

Experimental approach to the problem

A cross-sectional, repeated measures design was used to investigate the kinematics and kinetics of the deadlift exercise performed explosively, with and without the inclusion of chain resistance. Athletes with experience in performing ERT with chains took part in the study. Each athlete performed the deadlift with 30, 50 and 70% 1RM loads across four conditions: 1) submaximal velocity (SMAX); 2) maximal velocity (MAX); 3) maximal velocity with 20% 1RM chains (MAX20); and, 4) maximal velocity with 40% 1RM chains (MAX40). SMAX and MAX conditions provided a constant barbell resistance using standard weightlifting plates. Variable resistance was created for MAX20 and MAX40 conditions by using a combination of weightlifting plates and chains. The SMAX condition was included to provide a point of comparison which could be used to determine if the kinematics and kinetics changed when athletes increased their repetition velocity from cadences used in traditional strength training regimes to maximal cadences used in ERT. Multiple chain and barbell loads were incorporated to investigate their individual and combined kinematic and kinetic effects.

Subjects

Twenty three experienced resistance trained athletes (15 powerlifters and 8 rugby union players) volunteered to participate in this study (age: 26.8 ± 5.9 yr; stature: 180.5 ± 4.2 cm; mass: 107.5 ± 21.0 kg; deadlift 1RM: 227.1 ± 49.3kg; deadlift 1RM/mass: 2.2 ± 0.4; resistance training experience: 10.7 ± 4.1 yr). Each of the athletes regularly performed ERT and had a minimum of one year’s resistance training experience using chains. Prior to experimental testing participants were notified about the potential risks involved and gave their written informed consent. Approval for this study was provided by the ethical review panel at Robert Gordon University, Aberdeen, UK.

Study design

Data were collected for each subject over two sessions separated by one week. The first session was performed in the gymnasium and involved 1RM testing in the deadlift. During the second session subjects reported to the laboratory where they performed the deadlift with 30, 50 and 70% 1RM loads across four conditions (SMAX, MAX, MAX20 and MAX40). Kinematic and Kinetic variables were analyzed during the second session only. Ten subjects performed the second testing session on two occasions separated by one week to assess inter-trial reliability.

Session 1 (1RM Testing Procedures)

All subjects were experienced weightlifters who regularly performed 1RM tests and could predict their maximum strength accurately. Based on a 1RM load predicted from performance in recent training sessions subjects performed a series of warm-up sets and up to 5 maximal attempts. A 2 to 4 minute rest period was provided between maximal attempts with the heaviest load lifted selected for analysis. All deadlifts were performed with a conventional shoulder width stance and deemed to be successful if the barbell was not lowered at any point during the ascent and upon completion of the movement the body posture was erect, the knees were straightened and shoulders retracted. Once 1RM testing was complete, subjects performed a single deadlift repetition at maximal velocity with 30, 50 and 70% of their 1RM. Displacement of the barbell was recorded to calculate the chains required for the second testing session.

Session 2 (Velocity and Chain Testing Procedures)

Subjects performed their own specific warm-up which generally consisted of 3 to 5 minutes jogging on a treadmill, and then 2 to 4 deadlift sets with a light load (e.g., < 40% 1RM) for 6 to 10 repetitions. Once suitably prepared, subjects performed the SMAX trials with 30, 50 and 70% 1RM loads in ascending order. Subjects were instructed to perform the repetitions at the velocity they would normally use in training sessions aimed at developing muscular hypertrophy (i.e., at a controlled submaximal velocity). Velocity was not standardized in the submaximal condition to establish the preferred lifting velocity of trained athletes and to determine if the intention to increase lifting speed from normal to maximum altered the kinematics and kinetics of the exercise. Following the SMAX trials subjects performed maximal velocity trials (MAX, MAX20 and MAX40) with 30, 50 and 70% 1RM loads in a randomized order. Seven-foot chains varying in size from 2.54 to 0.64 cm links were attached to the barbell for MAX20 and MAX40 conditions so that the chain mass at the top of the movement was equal to 20 or 40% of the lifters 1RM respectively. The average resistance lifted in the chain and non-chain conditions were equated by subtracting half the mass of the chains at the top of the movement from the initial barbell load. For example, during the MAX20 conditions the barbell load was reduced by 10% of the lifters 1RM so that the total resistance was 10% less than the constant barbell condition at the bottom, equal at the midpoint, and 10% greater at the top. Subjects were instructed to hold the barbell stationary at the end of the concentric action to calculate the chain mass raised from the floor. The actual mass of chains lifted by the group was equal to 21.1 ± 3.6% 1RM and 38.2 ± 4.9% 1RM. Subjects were instructed to keep their elbows straight throughout the deadlift and not to jump with the weight. If these requirements were not met the trial was repeated. Subjects were permitted to elevate their heels at the terminal stage of the movement as long as the forefoot remained in contact with the ground. Two repetitions were performed in each trial to calculate intra-trial reliability. The repetition that produced the greatest peak velocity was selected for further analysis.

Measurement of Kinematic and Kinetic Variables

Trials were performed with a separate piezoelectric force platform (Kistler, Type 9281B Kistler Instruments, Winterthur, Switzerland) under each foot, in a capture area defined by a seven-camera motion analysis system (Vicon MX, Vicon Motion Systems, Oxford, UK). The geometric centre of the external load was tracked in three-dimensional space by placing retroreflective markers at the ends of the barbell and calculating the position of the midpoint. Marker position and ground reaction force data were captured at 200 and 1200Hz respectively. The area under the VGRF-time curve was integrated using Simpson's Rule to calculate impulse. Velocity and acceleration were calculated by taking the first and second derivative of the marker position data using a Lagrangian five point differentiation scheme. Relative phase of acceleration was calculated by expressing the positive acceleration data relative to the duration of the repetition and the total vertical displacement of the barbell. Instantaneous power was calculated as the product of the VGRF and corresponding barbell vertical velocity. The starting point of the concentric action was defined as the point where the estimated geometric centre of the barbell was raised 2 mm vertically above its initial resting position. The end of the concentric action was defined as the point where the estimated geometric centre of the barbell reached maximum vertical elevation.

Statistical Analysis

Intraclass correlation coefficients (ICC's) were calculated to assess intra- and inter-trial reliability for each variable analyzed. Two distinct sets of analyses were made to compare: a) the effect of repetition velocity (SMAX and MAX) on lifts without the use of chains; and b) the effect of different chain conditions (MAX, MAX20, MAX40) on lifts performed at maximal velocity. Potential kinematic and kinetic differences between submaximal and maximal velocity lifts performed without the use of chains were analyzed using a 2x3 (velocity x load) repeated measures ANOVA. Potential kinematic and kinetic differences between chain conditions performed at maximal velocity were analyzed using a 2x3 (chain-condition x load) repeated measures ANOVA. Significant main effects were further analyzed with Bonferroni adjusted pair-wise comparisons. Statistical significance was accepted at $p < 0.05$. All statistical procedures were performed using the SPSS software package (SPSS, Version 16.0, SPSS Inc., Chicago, IL).

RESULTS

Similarly high ICC values were obtained for intra- (0.8 to 0.96) and inter-trial reliability (0.8 to 0.95) respectively. Variables measured during deadlifts performed at submaximal and maximal velocities without chains are displayed in Table 1. Significant interaction effects ($p < 0.05$) of load and repetition velocity were obtained for all variables measured except peak rate of force development and acceleration phase expressed relative to displacement of the barbell. Interaction effects demonstrated that augmentation of variables induced by increasing velocity from submaximal to maximal diminished as the external load increased. Performing repetitions at maximal velocity significantly increased ($p < 0.05$) the magnitude of all variables measured except impulse.

Significant interaction effects of load and chain-condition were obtained for average velocity, peak velocity, average power, and impulse ($p < 0.05$). Interaction effects demonstrated that the relative increases and decreases of mechanical variables as a result of including chains became more pronounced as the barbell load increased. The inclusion of chains significantly increased peak force and impulse ($p < 0.05$), and significantly decreased average velocity, peak velocity, average power, peak power, and peak rate of force development ($p < 0.05$) (Figure 1).

To investigate whether the inclusion of chains enabled force production to be maintained throughout the concentric action, force values were averaged across 10% intervals of the vertical barbell displacement and normalized to the peak value generated during the repetition (Figure 2). Results illustrated that the inclusion of chains enabled greater relative force to be maintained during the latter portions of the concentric action.

DISCUSSION

The results of the current investigation reveal that performing the deadlift explosively enhances a range of kinematic and kinetic variables compared to lifting with a submaximal velocity. Contrary to the commonly held belief that all traditional resistance exercises require the lifter to decelerate the load for the majority of the concentric action, the results of the study demonstrate that the deadlift can be used to maintain positive acceleration for most of the upward lifting phase. When combining the acceleration phase data with the large force and power values recorded, the results are consistent with recent research suggesting it may be advantageous to perform traditional resistance exercises such as the deadlift explosively within periodized programs aimed at developing muscular power (17).

The present study is the first to test the theory that the inclusion of chains with a traditional resistance exercise enables greater force production to be maintained during the latter stages of the concentric action. The results confirmed the theory and illustrated that larger relative forces were maintained when heavier chains were included. The results also demonstrated that the inclusion of chains had a significant effect on peak and average values recorded for a range of kinematic and kinetic variables. The inclusion of chains increased peak force and impulse and decreased average velocity, peak velocity, average power, peak power, and peak rate of force development compared to deadlifts performed without chains using the same average load. The effects of chains were influenced by the magnitude of the chain and barbell resistance, with larger effects obtained when heavier chain and barbell loads were used.

Studies investigating the effects of free-weight repetition velocity have focused on comparisons of submaximal velocities categorised as fast, moderate and intentionally slow (20, 25, 36). Results have demonstrated that fast repetitions produce the greatest force, power, rate of force development, muscle recruitment and overall training volume (20, 25, 36). From the previous studies fast repetitions were defined as cadences of one second or less (1, 30). In the current investigation the group performed the 30 and 50% 1RM SMAX trials in less than one second demonstrating that the preference of well-trained athletes is to perform light repetitions in the deadlift at fast velocities. Despite individual variation in self-selected velocity for submaximal trials, the instruction to lift the load as fast as possible resulted in significantly lower repetition durations with all three loads completed in less than one second (Table 1). The only mechanical variable in the current study to exhibit a decrement when repetitions were performed explosively was impulse. It is widely recognized that the factors of impulse (force and duration of muscular action) are important mechanical variables that regulate adaptations to resistance training (11). It has also been suggested that impulse itself may be an important variable influencing adaptation (11). However, a limited number of studies have measured impulse during resistance exercise and knowledge of the practical significance remains incomplete (10, 12). In the context of training for the development of power it is unlikely that intentionally reducing velocity to increase impulse at the detriment of force, velocity, power and rate of force development would be beneficial.

A number of researchers have cautioned against including traditional resistance exercises with ERT due to the belief that the exercises require extensive periods of deceleration and reduced force to slow the barbell velocity to zero at the end of the concentric action (24, 32). The first investigation to examine force and acceleration profiles throughout the duration of a traditional resistance exercise was conducted by Lander *et al*, (26). Their results showed that when a submaximal load of 75% 1RM was lifted explosively in the bench press exercise approximately one quarter (26.5 ± 4.7%) of the exercise duration was spent decelerating the load (26). A similar experiment using a slightly heavier load of 81% 1RM was completed by Elliot *et al*, (16). The deceleration period reported by the authors was considerably greater than that found by Lander *et al*, (26) and shown to be longer in duration than the acceleration period (51.7% vs. 48.3% respectively). Elliot *et al*, (16) suggested that dissimilar results between the two studies may have been due to order effects from the different experimental protocols. Both Lander e*t al*, (26) and Elliot *et al*, (16) reported the phase acceleration data relative to the duration of the overall movement; however, it is not clear whether reporting acceleration data relative to time or displacement is more informative. When time is used to calculate the relative phase, segments of the movement with the lowest velocity will have greater influence on the reported value. In the current investigation the results demonstrated that the period of acceleration appears greater when reported relative to displacement (Table 1). Both methods of analysis revealed that the period of acceleration increased when the deadlift was performed at maximal velocity and with heavier loads.

The inclusion of chains with ERT has become a popular training practice based on anecdotal claims of effectiveness (28). The primary rationale for including chains is the assertion that variable resistance can address the perceived limitations of deceleration and reduced force production believed to occur during the latter stages of traditional resistance exercises. It has been theorised that increased resistance from chains during the exercise will enable force production to be maintained to the end of the movement (4, 38). The results from the present study are the first to confirm that the inclusion of chains can enable significantly greater relative forces to be maintained throughout the concentric action. However, the results show that a minimum barbell load and substantial amount of chain mass are required.

Previous studies investigating the effects of chain resistance have used comparatively much lighter chain loads than those used here. Ebben and Jensen (15) substituted 10% of the barbell mass with chains during performance of the back squat with a 5RM load. Based on research equating a 5RM load with a resistance of 80% 1RM (34), the chain mass substituted by Ebben and Jensen (15) equalled approximately 8% of the athletes' 1RM. Lighter chain resistances have been used in studies investigating the biomechanics of Olympic weightlifting exercises. Coker and colleagues substituted 5% of the subjects' 1RM for chain mass during performance of the snatch (8) and power clean (7). Ebben and Jensen (15) and Coker and colleagues (7, 8) each reported no significant effects of substituting chains for any of the biomechanical variables measured. It has been suggested that when chains are used to improve the stimulus of explosive resistance exercises the mass of chains should be greater than 15% of the athletes' 1RM (28). Prior to this investigation only a single study had examined the biomechanical effects of including chains with a mass approaching the suggested value. Baker and Newton (5) used an experimental protocol that compared a constant barbell resistance of 75% 1RM with a variable resistance that equalled 60% 1RM at the bottom of the movement and increased to a maximum 75% 1RM at the point of half the total vertical displacement. The variable resistance was shown to develop significantly greater mean and peak velocity values compared with the constant barbell resistance (5). It is likely that the increase in velocity reported by Baker and Newton (5) occurred at least in part because of different average loads lifted between the conditions. In the variable resistance trials the combined chain and barbell load was less than the constant barbell resistance during the bottom half of the exercise and did not increase beyond the constant barbell resistance at any point during the movement. As a result, the average load lifted was less in the variable condition and therefore an increase in movement velocity should be expected. In the present study the average loads in the variable and constant resistance conditions were equated to investigate the effects of including chains without the confounding influence of different average loads. Using this experimental protocol the results demonstrated that the inclusion of chains increased force and impulse, whilst concurrently reducing velocity, power and rate of force development (Figure 1). The reduction in peak and average velocity obtained with the inclusion of chains contradicts the previous findings reported by Baker and Newton (5). Dissimilar results are most readily explained by the equating of average loads between conditions in the present study. Figure 3 illustrates that velocity in the MAX20 chain condition (load closest to that used by Baker and Newton (5)) was greater than the constant barbell load until the overall resistances were of near equal magnitude. As the combined chain and barbell resistance continued to increase the velocity for the MAX20 chain condition progressively fell below the comparison trial. Overall, the slower velocities obtained for the variable resistance during the second half of the movement outweighed the initial improvements and as a result the average velocity with chains was lower than that obtained for the constant resistance. The reduction in velocity during the variable resistance trials was greater in magnitude than the concomitant increase in force, explaining why average and peak power values were also reduced when chain resistance was included. The results of the present study also demonstrated that the combination of heavier chain and barbell loads resulted in greater relative increases in force and impulse, and greater relative decreases in velocity, power and rate of force development (Figure 1).

The use of stiff rubber bands with free-weight exercises has traditionally been considered to provide the same variable resistance effect as chains (8, 18). More recently, researchers have begun to examine the differences between chains and rubber bands. McMaster *et al,* (29) reported that resistance changed linearly with displacement of chains, whereas, rubber bands were constructed from viscoelastic material that resulted in nonlinear changes in resistance. Using static measurements over a range of displacements McMaster *et al,* (29) reported that the length-tension relationship of rubber bands was best represented by quadratic polynomials where stiffness was at is greatest during the initial stage of elongation. In a recent review article evaluating the kinematics and kinetics of different resistance training practices Frost *et al,* (18) intimated that the different inertial properties of bands and chains may provide dissimilar mechanical effects. The concepts proposed by Frost *et al,* (18) were clarified by Arandjelović (3) who derived equations of motion for bands and chains attached to a barbell based on known forces and the work-energy principle (derivation of the equations presented by Arandjelović (3) are displayed in appendix A). The equations of motion presented by Arandjelović (3) were shown to be fundamentally different for the variable resistance materials. For a given amount of force the acceleration when attaching rubber bands was shown to be limited by the mass of the barbell and the stiffness and displacement of the rubber bands. When using chains the acceleration was shown to be limited by the mass of the chains, the mass of the barbell and the square of the system velocity. The different mechanical effects exhibited by rubber bands and chains are explained as suggested by Frost *et al,* (18) by the different inertial properties of the materials. Rubber bands have negligible mass and therefore contribute to resistance through displacement of the band only. In contrast, chains provide a substantial mass element that creates resistance by gravitational acceleration and through changes in momentum that occur when individual links are accelerated to the velocity of the barbell from initial stationary positions (3). Based on the different equations of motion established by Arandjelović (3) in most circumstances where the static properties of bands and chains are matched for ERT the acceleration and therefore velocity of the movement will be slower when using chains.

The altered dynamics that chains impose when they are attached to the barbell can be used to explain the direction of the results obtained in the present study. The submaximal loads used in the experimental protocol would have enabled relatively fast velocities to be produced in the early stages of the movement which would subsequently detract from the amount of force applied as the chains increased the overall resistance through changes in momentum of the individual links (see equation 6 in Appendix A). The increased resistance would limit acceleration and provide an additional mechanism to explain the decreased average and peak velocity values obtained when including chains. When comparing the velocity of different conditions across the range of motion it is evident that the mass of the chains had an important effect (Figure 3). The equation of motion derived for the combined barbell and chain load illustrates that the velocity term which detracts from the system acceleration is multiplied by a coefficient equal to the mass per unit length of the chain (see equation

6 in Appendix A). The coefficient for the MAX40 condition would equal double the value of the coefficient for the MAX20 condition. This difference may explain why velocity values during the MAX40 trial fell substantially below the lighter chain condition during the first half of the movement even when the combined chain and barbell masses were lighter. The increase in peak force obtained with lifts that included chains may have occurred due to the decrease in velocity of the movement and the well established inverse relationship between force and velocity established for free-weight exercises (14, 17, 33). In addition, the increase in absolute load experienced during the second half of the movement may have also contributed to increases in peak force obtained for heavier chain and barbell load conditions.

A limited number of studies have investigated the effects of combining chains with free-weight exercises over multiple training sessions. McCurdy *et al,* (27) compared the effects of performing the traditional bench press versus a chain variation where the entire load except from the barbell was comprised of chain resistance. The study included twenty-seven college baseball players who were allocated between two groups that performed either the traditional or chain bench press during two weekly upper-body strength sessions over a nine week training period. The authors selected dependent measures to assess improvements in strength and perceived levels of shoulder pain. Strength improvements were measured using the 1RM traditional bench press and the 1RM chain bench press. Both groups demonstrated significant strength improvements in the traditional and chain 1RM tests with no significant differences reported between groups. Despite the non-significant results, the study showed that athletes who performed the chain variation in training demonstrated greater post-intervention strength increases in the 1RM chain bench press (12.9% vs.

6.9%). These results suggest that a training specificity effect occurs when using chain resistance. The results of the study also demonstrated a non-significant but substantial 3-fold lower score for shoulder pain exhibited by athletes training with the chain bench press. The authors attributed the lower pain scores to reduced loading that occurs during the chain bench press at the bottom portion of the movement.

In the most recent longitudinal investigation of chain resistance Ghigiarelli *et al,* (19) compared the effects of training with a constant barbell resistance or a combination of barbell resistance and rubber bands or chains. The study included thirty-six college football players who performed four resistance training sessions per week over a seven week training intervention. The weekly training program featured alternating upper- and lower-body strength sessions where each athlete performed assistance exercises and the squat or bench press using the particular variation they were assigned to. The authors reported that all three groups significantly improved their 1RM strength with no significant differences established between groups. Ghigiarelli *et al,* (19) also reported greater non-significant improvements in peak power for the variable resistance groups. Combining the results obtained by McCurdy *et al,* (27) and Ghigiarelli *et al,* (19) it is evident that chains can be combined with free-weight resistance to improve strength. In addition, it appears that the inclusion of chains may provide additional advantages over a constant barbell resistance for certain biomechanical and physiological variables. The majority of longitudinal studies that have investigated the effects of combining variable resistance material with free-weights have used rubber bands (2, 13, 19, 21, 35). The results have clearly demonstrated that the addition of rubber bands can significantly improve measures of strength and power and those improvements are generally significantly larger than those achieved when using a constant resistance (2, 13, 35). However, on the basis of the mechanical differences highlighted in the present study it would be inappropriate to generalize the more positive results obtained for rubber bands to the use of chain resistance.

Accurate conclusions regarding the effectiveness of combining chain resistance with free-weights are difficult to make because of a variety of unresolved factors. The limited amount of research that has been conducted on the use of chains in comparison to the large number of potential chain and barbell load combinations considerably limits present understanding. In addition, kinematic and kinetic analyses of the effects of including chain resistance have thus far been restricted to single repetitions. Crewther *et al*, (11) have previously highlighted the need for biomechanical studies to investigate kinematics and kinetics over multiple sets and repetitions to more accurately establish the acute mechanical stimulus of a given exercise strategy. An additional factor that is likely to impact on the effectiveness of using chain resistance is the choice of exercise. The first study to investigate potential kinematic and kinetic changes when including chain resistance was conducted using the squat (15). The squat may be an effective exercise to combine with chains as it has been suggested that exercises that include an initial eccentric lowering phase may benefit from a postactivation potentiation (PAP) effect when variable resistance material is included (5). The proposed mechanism for the PAP effect states that increased resistance at the top of the exercise when using chains or rubber bands enhances preparatory muscle stiffness and neuromuscular drive, which if maintained to the bottom of the movement could augment performance during the concentric action (5). Further research to establish the likelihood and potential impact of an augmentary neuromuscular stimulus during stretch-shortening cycle exercises with variable resistance is required. Following investigation of the squat exercise multiple studies examined the effects of including chain resistance with the snatch and power clean (7, 8). Due to the ballistic nature of Olympic weightlifting exercises it is unlikely that the inclusion of chains would improve the primary stimulus as force and acceleration are thought to be maintained when using a constant barbell resistance (22). There have been anecdotal claims that the inclusion of chains with Olympic weightlifting exercises may enhance motor control and balance (6). However, research thus far has failed to include dependent measures able to discern whether these claims are valid. In the present study the deadlift was used in part to generate kinematic and kinetic data without the possible confounding effects from an initial eccentric action. From a practitioner's perspective the use of the deadlift in the present study provides novel information on an exercise that is currently recommended to be used with chain resistance and has been shown to be combined with chains as frequently as the squat (6, 37, 40). Based on unresolved factors discussed above, it is clear there is need for further research on the use of chain resistance. In particular, biomechanical and physiological research should investigate the effects of using chains over multiple sets and repetitions. In addition, research comparing the effects of chains on multiple exercises with the same population should include EMG measures to assess the potential impact of variable resistance material on the nervous system.

PRACTICAL APPLICATIONS

The current investigation has shown that the deadlift can be used to generate large force and power values when performed explosively. In contrast to the commonly held belief that all traditional resistance exercises include extensive periods of deceleration and reduced force production, the results of the present study demonstrate that the deadlift can enable positive acceleration to be maintained for the majority of the exercise even when using very light loads. Collectively, the results suggest that it may be beneficial to include exercises like the deadlift in structured periodized programs aimed at developing muscular power.

Those who wish to modify exercises to increase force production during the later stages of the concentric action may consider the inclusion of chain resistance. The goal should not be to perfectly match strength curves of individuals to create isokinetic movements, but to provide a variable resistance that alters the acceleration profile of the exercise enabling greater force to be maintained throughout the movement. The results of the present study demonstrate that chains can be used to maintain large relative forces throughout the concentric action and that greater relative force is maintained when using heavier barbell and chain loads. However, practitioners and athletes should be aware that in conjunction with increases in force and impulse, the inclusion of heavy chains may reduce velocity, power and rate of force development depending on various acute program variables such as exercise selection and the initial barbell load. Practitioners and athletes should also be aware that the mechanical effects of rubber bands and chains are likely to have different effects on the biomechanical stimulus of an exercise and that the divergent effects are likely to be magnified when using larger variable resistances.

Acknowledgments

The results of the present study do not constitute endorsement by the authors or the NSCA.

Conflicts of interest: None

Sources of funding: None

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Figure Legends

Figure 1-Kinematic and kinetic data for chain conditions (MAX20, MAX40) with 30, 50 and 70% 1RM loads. Data are expressed as a percentage difference relative to the values obtained for the corresponding non-chain condition (MAX). Peak force = PF, peak velocity = PV, peak power = PP, peak rate of force development = PRFD, impulse = IMP. Error bars represent + 1SD

Figure 2-Mean (+ 1SD) vertical ground reaction forces during the concentric phase of maximal velocity repetitions (MAX, MAX20, MAX40). Data are expressed as a percentage relative to the peak force value obtained for each condition. * Significant ($p < 0.05$) difference between MAX and MAX20 for corresponding segment of movement. [#] Significant ($p < 0.05$) difference between MAX and MAX40 for corresponding segment of movement. [†] Significant ($p < 0.05$) difference between MAX20 and MAX40 for corresponding segment of movement.

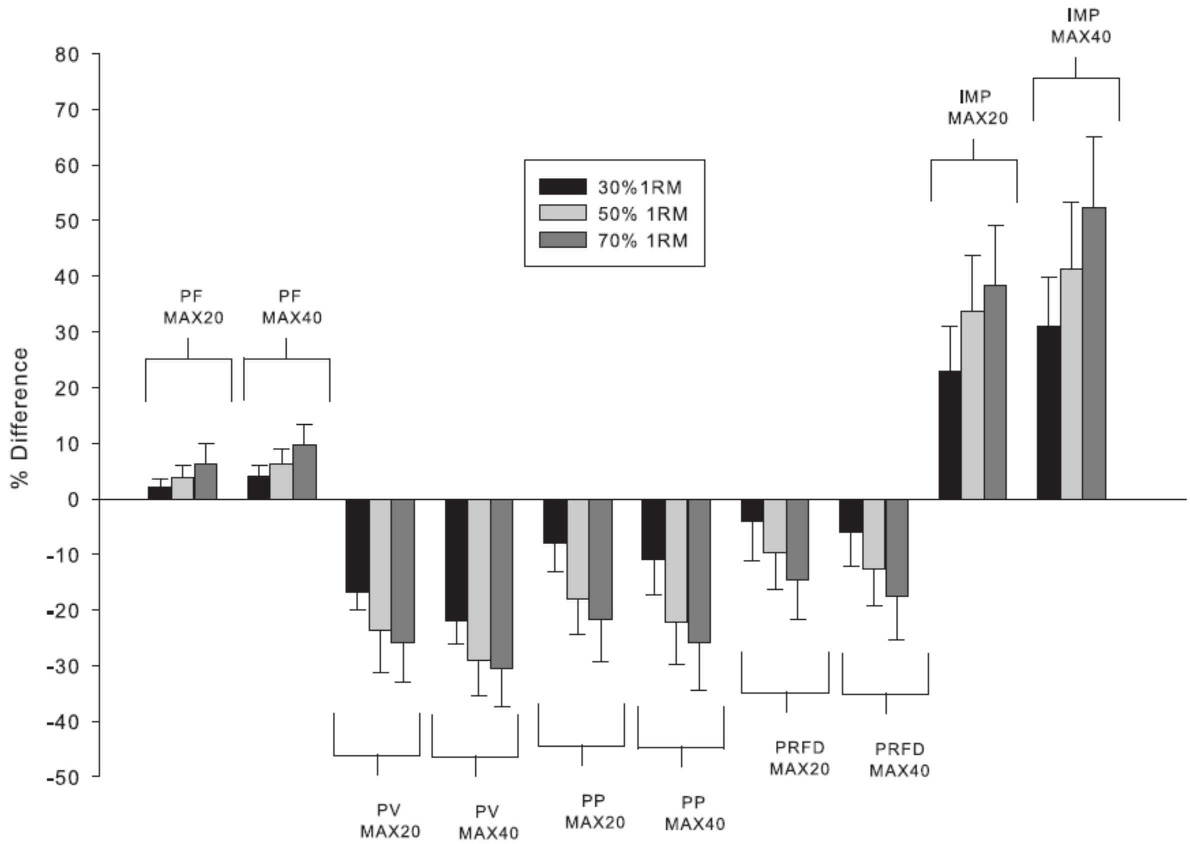
Figure 3-Velocity during the concentric phase of maximal repetitions (MAX, MAX20, MAX40) with the 50% 1RM load. Values are averaged over 10% intervals of the vertical barbell displacement and interpolated to assist with comparison. *

Significant ($p < 0.05$) difference between MAX and MAX20 for corresponding segment of movement. # Significant ($p < 0.05$) difference between MAX and MAX40 for corresponding segment of movement. † Significant ($p < 0.05$) difference between MAX20 and MAX40 for corresponding segment of movement. Standard deviations across the ROM were similar between conditions and are consequently illustrated on a selection of trials to maintain clarity.

Table 1. Kinematic and kinetic data for deadlifts performed without chains at self selected submaximal velocity (SMAX) and maximal velocity (MAX). * Significant difference between SMAX and MAX for corresponding load (*p* < 0.05).

	SMAX 30% 1RM	SMAX 50% 1RM	SMAX 70% 1RM	MAX 30% 1RM	MAX 50% 1RM	MAX 70% 1RM
Repetition Duration (s ±SD)	0.93 * (±0.14)	1.08 * (±0.20)	1.29 * (±0.24)	0.69 * (±0.11)	0.81 * (±0.16)	0.97 * (±0.19)
Peak Force (N ±SD)	2178 * (±351)	2578 * (±475)	2954 * (±487)	2774 * (±439)	2899 * (±446)	3060 * (±457)
Average Velocity (m/s ±SD)	0.66 * (±0.11)	0.57 * (±0.12)	0.66 * (±0.12)	1.37 * (±0.11)	1.13 * (±0.15)	0.81 * (±0.17)
Peak Velocity (m/s ±SD)	1.12 * (±0.21)	0.96 * (±0.19)	0.82 * (±0.17)	2.20 * (±0.23)	1.70 * (±0.20)*	1.20 * (±0.22)
Average Power (W ±SD)	1012 * (±311)	1108 * (±357)	1149 * (±337)	1965 * (±419)	2289 * (±383)	1813 * (±319)
Peak Power (W ±SD)	1710 * (±487)	1902 * (±538)	1966 * (±487)	4247 * (±695)	4021 * (±624)	2927 * (±480)
Peak RFD (N/s ±SD)	4887 * (±2432)	5631 * (±2727)	6408 * (±2606)	7658 * (±3853)	9485 * (±3911)	11219 * (±4362)
Acceleration Phase [% Overall Displacement] (±SD)	67.7 * (±7.3)	73.9 * (±9.8)	80.1 (±10.3)	73.2 * (±7.2)	79.4 * (±9.5)	84.9 (±12.2)
Acceleration Phase [%Overall Time] (±SD)	57.6 (±7.7)	58.4 * (±8.5)	69.0 (±10.7)	62.9 (±12.0)	69.0 * (±10.2)	73.5 (±11.3)
Impulse (N · m ±SD)	1740 * (±317)	2555 * (±452)	3903 * (±711)	1020 * (±122)	1468 * (±206)	2539 * (±499)

Figure 1



% Difference
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
30%1RM
50% 1RM
70% 1RM
PF
MAX20
PF
MAX40
PV
MAX20
PV
MAX40
PP
MAX20
PP
MAX40
PRFD
MAX20
PRFD
MAX40
IMP
MAX20
IMP
MAX40

Figure 2

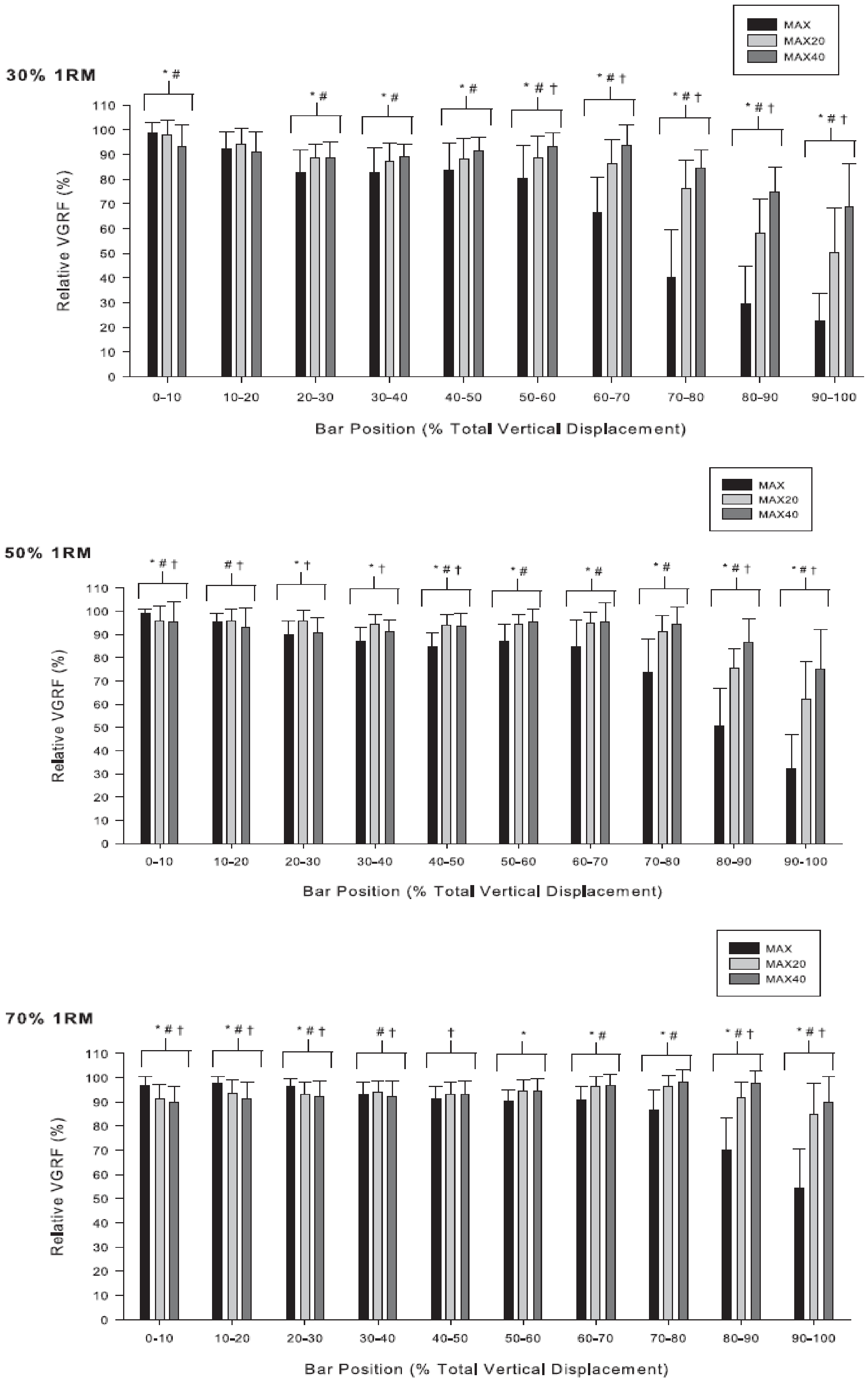
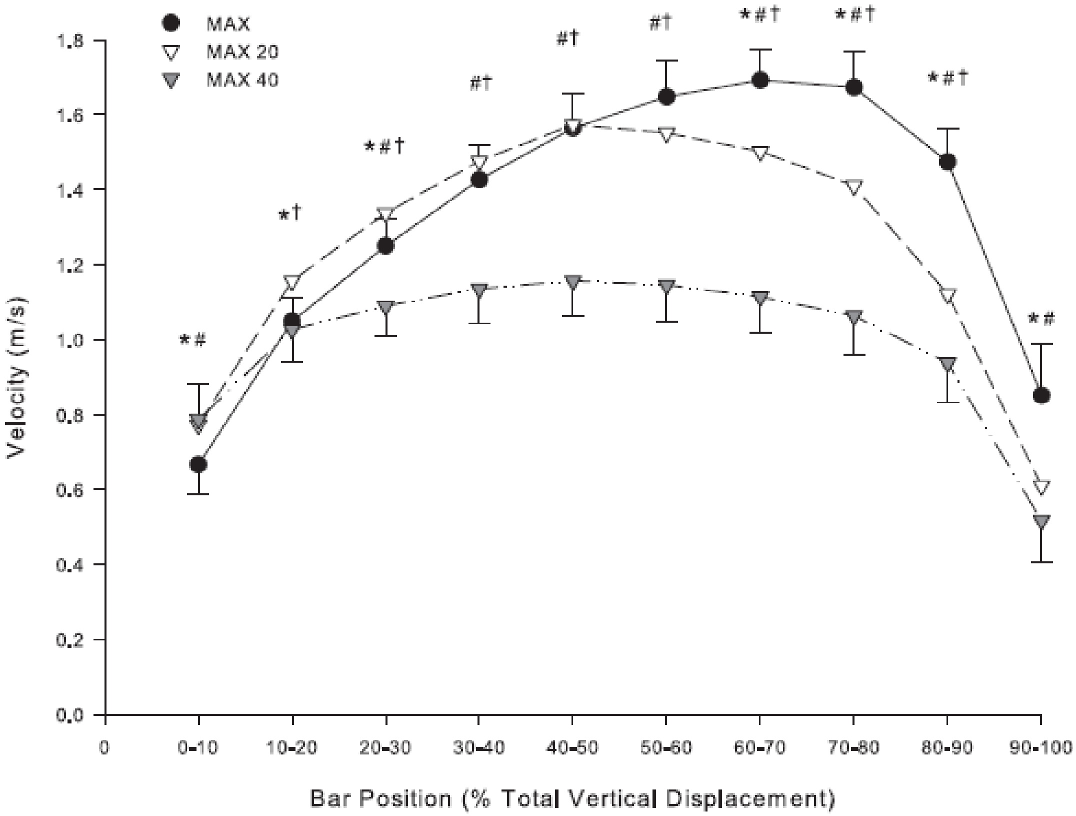

MAX
MAX20
MAX40
30% 1RM
Relative VGRF (%)
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
Bar Position (% Total Vertical Displacement)
50% 1RM
70% 1RM

Figure 3


MAX
MAX 20
MAX 40
Velocity (m/s)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
Bar Position (% Total Vertical Displacement)
*#
*†
*#†
#†
#†
#†
*#†
*#†
*#†
*#

Appendix A

Appendix A. Derivation of equations of motion for the barbell, barbell + bands and barbell + chains, based on the work-energy principle

Barbell:

The work done on the barbell is equal to the sum of the change in potential energy and change in kinetic energy of the barbell respectively:

$$F\,dz = mg\,dz + d\left(\frac{1}{2}m\dot{z}^2\right). \quad (1)$$

Where F is the force applied, dz is the infinitesimal displacement in the vertical direction, m is the mass, g is the acceleration due to gravity, z is the vertical position and a dot over the symbol indicates time differentiation (thus $\dot{z}$ is the vertical velocity and $\ddot{z}$ is the vertical acceleration).

Dividing both sides of (1) by dt gives,

$$F\frac{dz}{dt} = mg\frac{dz}{dt} + \frac{d}{dt}\left(\frac{1}{2}m\dot{z}^2\right),$$

Carrying out time differentiation and using the chain rule for differentiation of the change in kinetic energy of the barbell gives,

$$F\dot{z} = mg\dot{z} + m\dot{z}\ddot{z},$$

Solving for acceleration gives,

$$\ddot{z} = \frac{F}{m} - g. \,(2)$$

Barbell + Rubber Band:

For the following equation it is assumed that the resistance caused by the rubber band is linear and depends upon the stiffness (k) and the displacement (z). The work done on the barbell and rubber band is then equal to the sum of the change in potential energy of the barbell, the change in elastic energy of the rubber band, and the change in kinetic energy of the barbell respectively:

$$F\,dz = mg\,dz + d\left(\frac{1}{2}kz^2\right) + d\left(\frac{1}{2}m\dot{z}^2\right). \quad (3)$$

Dividing both sides of (3) by dt gives,

$$F\frac{dz}{dt} = mg\frac{dz}{dt} + \frac{d}{dt}\left(\frac{1}{2}kz^2\right) + \frac{d}{dt}\left(\frac{1}{2}m\dot{z}^2\right),$$

Carrying out time differentiation and using the chain rule for differentiation of the change in elastic energy of the rubber band, and change in kinetic energy of the barbell gives,

$$F\dot{z} = mg\dot{z} + kz\dot{z} + m\dot{z}\ddot{z},$$

Solving for acceleration gives,

$$\ddot{z} = \frac{F - kz}{m} - g. \quad (4)$$

Barbell + Chain:

For the following equation the mass of the chain added to the barbell is expressed as αz, where α is the mass per unit length of chain. The work done on the barbell and chain is then equal to the sum of the change in potential energy of the barbell, the change in potential energy of the chain, the change in kinetic energy of the barbell, and the change in kinetic energy of the chain respectively:

$$F\,dz = mg\,dz + \alpha zg\,dz + d\,(\,0.5m\dot{z}^2 + 0.5\alpha z\dot{z}^2\,).\ (5)$$

Dividing both sides of (5) by dt gives,

$$F\,\frac{dz}{dt} = mg\,\frac{dz}{dt} + \alpha zg\,\frac{dz}{dt} + \frac{d}{dt}\left(\frac{1}{2}m\dot{z}^2 + \frac{1}{2}\alpha z\dot{z}^2\right),$$

Carrying out time differentiation and using the chain rule for differentiation of the change in kinetic energy of the barbell, and the product and chain rule for differentiation of the change in kinetic energy of the chain gives,

$$F\dot{z} = mg\dot{z} + \alpha zg\dot{z} + m\dot{z}\ddot{z} + \frac{1}{2}\alpha\,(\dot{z}^3 + 2z\dot{z}\ddot{z}),$$

Rearranging and using $\ddot{z}$ and $\dot{z}$ as a common factors gives,

$$\ddot{z}\dot{z}(m + \alpha z) = \dot{z}\left(F - g(m + \alpha z) - \frac{1}{2}\,\alpha\dot{z}^2\right),$$

Solving for acceleration gives,

$$\ddot{z} = \frac{F - \frac{1}{2}\alpha\dot{z}^2}{m + \alpha z} - g.\ (6)$$