Practical applications of biomechanical principles in resistance training: The use of bands and chains

Lake, Jason P; Swinton, Paul A.; Keogh, Justin

Published in:
Journal of Fitness Research

FitnessResearch.edu.au

ORIGINAL RESEARCH

PRACTICAL APPLICATIONS OF BIOMECHANICAL PRINCIPLES IN RESISTANCE TRAINING: THE USE OF BANDS AND CHAINS

Paul Swinton[1], Justin Keogh[2, 3, 4], Jason Lake[5]

[1] School of Health Sciences, Robert Gordon University, Aberdeen, UK.

[2] Faculty of Health Sciences and Medicine, Bond University, Australia

[3] Sports Performance Research Institute New Zealand, AUT University, Auckland, New Zealand

[4] Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Australia

[5] Department of Sport and Exercise Sciences, University of Chichester, Chichester, UK

Corresponding author: Paul Swinton

School of Health Sciences, Robert Gordon University, Aberdeen, UK

Tel: 01224 263361, Email: p.swinton@rgu.ac.uk

ABSTRACT

In recent years, it has become popular for athletes and recreational trainers to perform resistance training with the addition of bands and chains. In this paper, we considered the advantages of manipulating an exercise to match the resistance provided with the force capabilities of the lifter, which generally change throughout the movement. We explain that bands and chains can be used to manipulate a variety of exercises that have the potential to enhance performance in sport and in many daily tasks. Whilst there are many similarities between the use of bands and chains for resistance training, we note that there are key differences and discuss the biomechanics of each material separately. In particular, we discuss that chains provide resistance primarily in the vertical plane and the resistance is linearly related to the displacement of the barbell. In contrast, bands can be set up to produce substantial horizontal forces in addition to the primary resistance force that often acts in the vertical direction. Also, research has demonstrated that bands provide a resistance force that is related in a curvilinear fashion to the displacement of the barbell. After introducing the main biomechanical features associated with each type of resistance material, we present findings from the strength and conditioning literature that has demonstrated the potential for bands and chains to improve the stimulus associated with strength and power training. At present, a more compelling evidence base has emerged for the use of bands in resistance training, particularly with regard to the development of power. It is not known whether this asymmetry reflects the greater number of studies conducted with bands or is influenced by methodological differences between studies. However, we also discuss the possibility that different inertial properties of bands compared with chains may make that former a more effective choice for the development of power. We hope that exercise professionals will benefit from this knowledge and obtain insight into how an understanding of biomechanical principles can assist with prescribing contemporary training regimes.

ISSN 2201-5655

INTRODUCTION

In parts 1 and 2 of this review series [1; 2], we discussed a range of mechanical and neuromechanical concepts that exercise professionals can explore to manipulate the training stimulus associated with conventional resistance training exercises. Initially, we discussed how outputs such as torques and joint forces can be altered through manipulation of factors including joint range of motion, body orientation, exercise selection and position of the external load. We then introduced Newton's second law of motion and discussed how it can be used to derive pivotal force-time and force-velocity relationships. Finally, we discussed how a range of factors including exercise technique and load selection can affect these force relationships, thereby influencing training gains for sports performance. The purpose of part 3 of this review series is to demonstrate how these various aforementioned biomechanical concepts can be applied to the alternative resistance training practice of applying bands and chains. This information will provide the exercise professional with greater understanding of a very popular contemporary practice used to manipulate the training stimulus experienced by clients.

IMPORTANCE OF THE FORCE-TIME CURVE

In part 2 of this review series [2], we discussed, in some depth, the force-time curve and its importance in assessing the stimulus provided by a specific resistance exercise. We noted that three distinct force-time curves are generated: 1) ascending, where the ability to produce force increases as the movement progresses; 2) descending, where the ability to produce force decreases as the movement progresses; and 3) bell-shaped, where the ability to produce force is nonlinear, first increasing and reaching maximum midway through the movement and then returning to a lower level as the movement is completed. From the perspective of developing maximum strength, the force-time curve provides the exercise professional with insight into progression options for specific exercises. For example, during performance of an exercise such as the squat (which features an ascending force-time curve), the lifter is limited by their ability to produce force during the bottom section of the movement. Once they have overcome this section, the potential to develop force increases and the remaining portion of the movement becomes progressively easier [3]. As a result, the lifter may produce substantially less force than they are capable of for large segments of the movement. However, if the exercise professional can manipulate the back squat in such a way to increase the overall resistance to match the lifters changing force capability, it is possible that the stimulus produced throughout the entire movement could be enhanced, resulting in greater training adaptations. Similarly, with an exercise such as the bent-over row (which features a descending force-time curve), maximum force is produced at the start of the lift and decreases as the bar is pulled closer to the trunk [4]. Therefore, in order to complete the repetition the load is selected so that it is relatively light at the beginning of the movement and subsequently matches the individuals reduced force capability at the end. If the exercise were modified so that the resistance was at its greatest at the beginning and decreased throughout the movement, again, the overall stimulus produced throughout the repetition could be increased and potentially lead to superior training adaptations. While the practicalities of modifying an exercise featuring a bell-shaped force-time curve are more complex, the same general principles apply.

MATCHING THE RESISTANCE AND FORCE-TIME CURVE

The potential to enhance the training stimulus by matching the individual's force capabilities to the resistance has been recognised for some time. Initially, cam- and lever-based systems were designed in attempts to alter the resistance to match the force capabilities of the individual [5]. With both cam- and lever-based systems a resistance-training machine is designed where the magnitude of the external load is fixed; however, the moment arm of the load changes throughout the range of motion to either increase or decrease the total resistance experienced [5]. For both mechanical systems a major limitation is the need to standardise the machine. Therefore, changes in the resistance generated throughout the movement may only match the force capabilities of certain individuals [6]. To overcome this limitation, Hislop and Perrine [7] introduced the concept of isokinetic exercise whereby a machine is used to rapidly alter the resistance to match any individuals force capability and cause the movement to progress at a constant speed. In modern machines, a motor reacting almost instantaneously provides the resistance to match input force. An extensive research base has demonstrated the effectiveness of isokinetic exercise and in some cases reported greater increases in strength compared with traditional resistance training methods [8]. However, many sports scientists and trainers argue that isokinetic devices and their associated exercise regimes suffer from the same limitations of any machine based training; that is, the exercises performed are generally very simple and do not transfer effectively to daily and sporting activities [9].

In attempts to better match resistance and force capabilities of an individual during more complex exercises (e.g., multi-articular movements such as squats and deadlifts), a number of exercise professionals currently recommend the inclusion of bands and chains [10,11]. In most applications, the bands and/or chains are attached to the barbell so that as the load is lifted the overall resistance increases. When using bands, they are generally anchored to the floor and as the barbell is elevated the bands stretch and provide more resistance with greater elongation. Alternatively, chains are generally only attached to the barbell so that as the barbell reaches its lowest position the majority of the links rest on the floor. As the barbell is elevated, links begin to unfurl and increase the overall resistance. For many years exercise professionals assumed that bands and chains provided comparatively indistinguishable mechanical effects. However, more recent research and experience with the materials have established that there are substantial mechanical differences and each form of resistance should be reviewed separately [9]. It should be noted that the mechanical effects of both bands and chains may be beneficial only for exercises that feature ascending force-time curves. Initially this restriction may appear to limit the

Figure 1. The deadlift performed with the addition of chains

Legend: Yellow arrows illustrate the chain links that are contributing to the overall resistance lifted at that specific point in the movement.

potential value of using the materials, however, many of the exercises routinely prescribed to fitness clients and athletes feature ascending force-time curves.

CHAIN RESISTANCE

The inclusion of chains provides additional resistance similar to weight plates that are added to every barbell. That is, the line of the resistance force created by the chains acts vertically downward due to gravity. Only chain links that are elevated from the floor add to the total resistance placed on the barbell (and therefore the resistance applied to the lifter). In figure 1, we can see that as the barbell is elevated, progressively more links add to the total resistance. At each point during the exercise, the overall weight lifted is equal to the weight of the loaded barbell plus the weight of the individual chain links elevated from the floor. In part 2 of this review series, we discussed Newton's second law of motion that was summarised by the equation

$$F=ma \qquad (1)$$

Where (N) refers to *net force*, while (kg) and (m/s^2) refer to *mass* and *acceleration,* respectively. Applying the equation to the lifting situation depicted in figure 1, we can see that If the load is held stationary then acceleration is equal to zero, and therefore both the left- and right-hand side of equation 1 must also equal zero. This means that the upward force applied by the lifter must equal the downward force of the load. Again, we can use equation 1 to calculate this downward force. Due to the effects of gravity all objects with mass (kg) are being accelerated downwards at approximately 9.81 m/s^2. Therefore a 100 kg load will create a downwards force equal to 981 N (Note: This downward force is appropriately referred to as the weight of the mass). If we return to the movement depicted in figure 1, we can see that if the lifter is required to provide enough force to simply hold the barbell stationary, then at each point of the movement the force would equal the weight of the loaded barbell plus the weight of the individual chain links elevated from the floor.

When using chains many exercise professionals ensure that at the top of the movement there is still some chain links left on the floor. This particular set-up avoids the chains swinging and potentially disrupting the overall movement. As a result, for

Figure 2. Standard chains used for resistance training

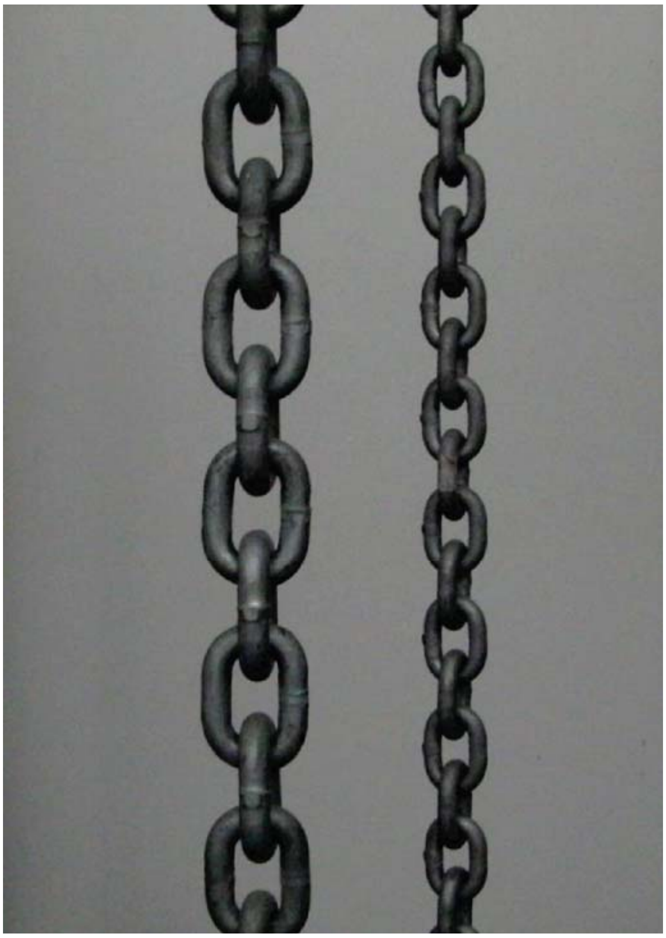
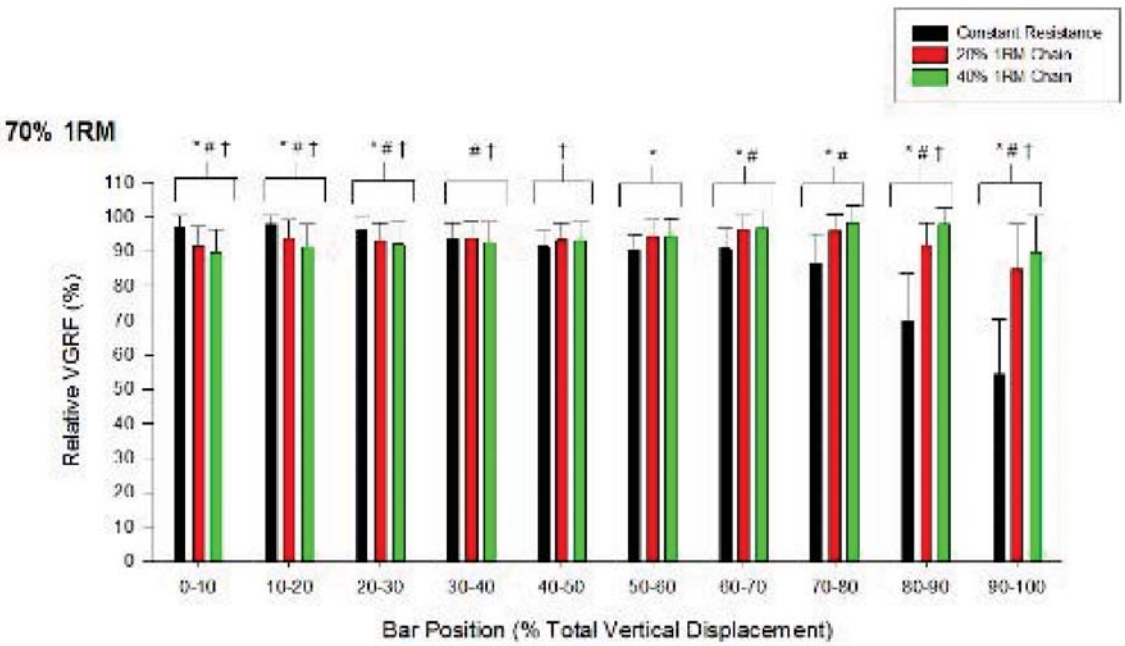


Figure 3. Manipulating the chain resistance used

each lifter there is a finite amount of vertical displacement that can occur and the primary means for altering the resistance provided by chains includes selecting the diameter of the links and/or the number of chains attached to the barbell. Figure 2 illustrates the standard diameters used for steel chain production. For a given displacement, chains with greater diameters will be heavier and therefore provide more resistance. Alternatively, figure 3 illustrates the multiple chain strategy whereby the weight of the chains can be doubled simply by adding a second identical chain. By using a standard set of weighing scales an exercise professional can determine the weight of the chain resistance that will be applied to the barbell at any point during the movement.

As the links in a given chain are identical, the weight added to the barbell increases linearly with upward vertical displacement (provided that links remain on the floor up to the end of the movement). This explains why the addition of chains best complement exercises that feature ascending force-time curves. For many individuals the deadlift exercise features an ascending force-time curve that may match the linear change in weight provided by the addition of chains. Swinton *et al.* [12] compared the forces produced when powerlifters performed the deadlift with resistance plates only and when chains were added so that at the top of the movement the weight of the chains were equal to 20% or 40% of the lifters one repetition maximum (1RM). In the trials where chains were added, a portion of the barbell weight was removed to better match the ascending force-time curve of the individual. For example, figure 4 illustrates the force produced by the lifter at different sections of the movement in the 70% 1RM comparison. For the standard barbell and weight plate condition, the weight was constant and equal to 70% of the lifters maximum. For the 20% 1RM chain condition, 10% of the barbell mass was removed so that at the bottom of the movement the load equaled 60% of the lifters 1RM and at the top of the movement the weight was equal to 80% 1RM. Finally, for the 40% 1RM chain condition, 20% of the barbell mass was removed so that at the

Figure 4 (Title): Force produced during deadlifts performed with a constant resistance and chains



Data are expressed as a percentage relative to the peak vertical ground reaction force (VGRF) obtained for each condition. * Significant difference ($p<0.05$) between constant load and 20% 1RM chain for the corresponding segment of the movement. # Significant difference ($p<0.05$) between constant load and 40% 1RM chain for the corresponding segment of the movement. † Significant difference ($p<0.05$) between 20% 1RM chain and 40% 1RM chain for the corresponding segment of the movement. Taken from Swinton et al. (2011).[12]

bottom of the movement the load equaled 50% of the lifters 1RM and at the top of the movement the weight was equal to 90% 1RM. Peak force increased in the 20% and 40% 1RM chain conditions by 8% and 10%, respectively, compared to the constant resistance condition. Figure 4, also shows that the inclusion of chains resulted in greater force production near the top of the movement. These results support the position that adding chains to exercises featuring ascending force-time curves enables the lifter to produce more force when they are at a greater mechanical advantage.

Longitudinal research has also been conducted to determine whether changes caused by the inclusion of chains can augment improvements in strength. McCurdy *et al.* [13] 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 recruited college baseball players and randomly allocated each athlete to a group that performed either the traditional bench press or chain bench press during two weekly upper-body strength sessions scheduled over a nine-week period. Both groups performed a linear periodisation program with each training session regularly comprising three exercises, whilst the relative resistance progressively increased from 60% 1RM in week one to 95% 1RM in week eight. The repetition range decreased from 5-8 repetitions in the early phases to 1-3 repetitions performed immediately prior to the final recovery week. Strength improvements were measured using a 1RM traditional bench press and a 1RM bench press where the barbell load was comprised entirely of chains. Both groups demonstrated improvements in each of the strength tests with no significant differences reported between the groups. Despite the non-significant between group results, the study revealed that the group performing the chain variation in training demonstrated greater post-intervention strength increases in the 1RM chain bench press (13% vs. 7%). These results suggest that a training specificity effect occurs when using chain resistance. The authors also monitored the athletes' shoulder and elbow pain throughout the interventions. The results demonstrated a non-significant but substantial 3-fold lower score for shoulder pain exhibited by athletes performing 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. For clients with a history of shoulder injuries or athletes such as baseball players that experience significant stress at the shoulder joint during sport specific practice, the potential to limit stress at the joint during resistance training whilst recruiting and strengthening associated muscles represents a substantial positive for the use of chains.

In a recent longitudinal study conducted to investigate the use of chain resistance, Ghigiarelli *et al.* [10] compared the effects of constant barbell resistance with a combination of barbell resistance and chain resistance. The study included thirty-six college football players who performed four resistance-training sessions per week over a seven-week period. The training program featured two upper-body and two lower-body strength sessions per week. An undulating periodisation design was implemented, with heavy loading sessions incorporating 4-6 repetitions in the beginning of the week, followed by lighter loading sessions targeting the development of power and comprising sets of 2-4 repetitions performed in the latter part of the week. During the upper- and lower-body sessions all athletes performed the same assistance exercises, with the difference being that each group either performed the squat and bench press with constant barbell resistance or with the addition of chains. Final analyses were conducted on the bench press only. The authors reported that both groups significantly improved their predicted 1RM strength with no significant differences established between groups (constant resistance = 5% improvement vs. chain resistance = 7% improvement). Ghigiarelli *et al.* [10] also reported greater improvements in peak power for the group that used chains (constant resistance = 1% improvement vs. chain resistance = 3% improvement). Combining the results obtained by McCurdy *et al.* [13] and Ghigiarelli *et al.* [10]

Table 1: Summary of intervention studies investigating the effects of strength and power training with chains and bands.

Study (year)	Participants	Groups	Setup used for bands and chains	Training Intervention	Major findings
Ataee et al. (2014) [24]	24 Male athletes (wrestlers and martial artists).	Strength training constant barbell resistance (n=12); strength training barbell resistance & chains (n=12).	Bench press and squat only: 85% 1RM at bottom of movement, 100% 1RM at very top of movement.	4 wks. 3 sessions/wk: Each session comprised the bench press and squat: 85% 1RM, 3 sets, 5 repetitions.	Group performing strength training with chains demonstrated significantly greater improvement in squat 1RM. No significant differences were obtained for upper body strength and upper-, lower-body power. However, effect sizes demonstrated a larger effect for the group that trained with chains for all tests.
Ghigiarelli et al. (2009) [10]	36 Division 1-AA male American football players.	Strength & power training constant barbell resistance (n=12); strength & power training barbell resistance & chains (n=12); strength & power training barbell resistance & bands (n=12).	Bench press only: Approximately 40 kg of additional chain mass was used. Elastic bands of unstated resistance were added.	7 wks. 4 sessions/wk: 1UB strength, 1LB strength, 1UB power, 1LB power. Strength: heavy loads 4-6 repetitions; Power: moderate loads 2-4 repetitions.	Combined data for groups demonstrated improved predicted 1RM and power during the bench press. No significant differences were obtained between groups. Larger magnitude improvements were obtained particularly in power tests for the chain and band groups compared with constant resistance group.
McCurdy et al. (2009) [13]	27 Division II male baseball players.	Strength training constant barbell resistance (n=14); strength training barbell resistance & chains (n=13).	Bench press only: Entire load was comprised of chains (except 20kg barbell) and based relative to participants 1RM chain bench press.	9 wks. 2 sessions/wk: UB only, linear periodized model with approx 3 exercises per session. Resistance increased from 60% 1RM in week one to 95% 1RM in week eight.	Both groups significantly improved 1RM barbell and 1RM chain bench press. No significant differences were reported between groups. Larger magnitude improvements were obtained particularly in 1RM chain bench press for the group training with chains.
Anderson et al. (2008) [17]	44 College aged athletes (basketball and hockey); 22 males and 22 females).	Strength training constant barbell resistance (n=21); strength training barbell resistance & bands (n=13).	Bench press and squat only: Barbell load was set so that it equalled 80% of the constant resistance at the bottom, and the combined barbell and band resistance was 20% greater at the top.	7 wks. 3 sessions/wk: 1UB strength, 1LB strength performed on alternating days. periodized in a wavelike progression, 5 to 8 exercises, 72-98% 1RM, 3-6 sets, 2-10 repetitions.	Group performing with bands improved their squat and bench press 1RM significantly more than the constant resistance group. In addition, a significantly greater increase in power produced during the vertical jump was also measured for those using bands.
Bellar et al. (2011) [16]	11 College aged untrained males.	Strength training with a crossover design. All participants performed constant barbell resistance; barbell resistance & bands.	Bench press only: Barbell load was set so that it equalled 85% of the constant resistance at the bottom, and the combined barbell and band resistance was15% greater at the top.	6 wks. 2 sessions/wk: 3wk's then crossover (1RM testing at the end of each 3wk's). Training consisted of bench press only. 85% 1RM, 5 sets, 5 repetitions.	ANCOVA revealed that the change in 1RM bench press was significantly greater after training with bands compared with constant resistance.
Cronin et al. (2003) [25]	40 College aged male and female athletes.	Power training constant resistance (n=14); power training with constant resistance & bands (n=14); control group (n=12).	Supine squat jump machine only: Bands provided a resistance force up to 360 N. The resistance of the sled was set so that the total resistance was equal between groups.	10 wks. 2 sessions/wk: LB only, each session comprised approx 5 lower body exercises, 8-15RM, 2-3 sets, 10-12 repetitions.	Both groups significantly improved strength and power values over a range of tests. Group training with bands improved lunge performance significantly more than the constant resistance group.
Heinecke et al. (2004) [15]	11 College aged males.	Strength & power training constant barbell resistance (n=6); strength & power training barbell resistance & bands (n=5).	Bench press only: Bands provided an additional resistance force up to 445 N.	5 wks. 2 sessions/wk: 1UB strength, 1UB power. Bands were used during the power session only. Power: 50% 1RM, 5 sets, 3 repetitions & 70% 1RM, 5 sets, 3 repetitions.	Group performing with bands improved their bench press 1RM significantly more than the constant resistance group. No significant differences were obtained between groups for seated medicine ball throw.
Joy et al. (2013) [11]	14 Division II male basketball players.	Daily undulating training program with constant barbell resistance (n=7); daily undulating training program with barbell resistance & bands (n=7).	Bench press and squat only: The barbell load was the same for both groups. Bands added resistance equal to 30% 1RM at the top of the movement.	7 wks. 4 sessions/wk: 1 strength, 2 power, 1 hypertrophy. Bands were used in only 1 of the power sessions.	Both groups significantly improved lean mass, vertical jump and strength as measured by 1RM bench press, 1RM squat, 1RM deadlift, and 3RM power clean. No significant differences were observed between groups, despite larger treatment effects measured in the squat, bench press and vertical jump for the group training with bands.
Rhea et al. (2009) [23]	48 Division I male athletes (baseball, track, football and basketball).	Strength training constant barbell resistance (n=16); Power training constant barbell resistance (n=16); Power training barbell resistance & bands (n=16).	Squat only: Bands that equalled 50% 1RM at the top of the movement were used. Barbell load was added so that the speed of the movement was the same as the group performing the power training with constant barbell resistance.	12 wks. 2-3 sessions/wk: LB only, each session included 5 exercises with an average of 4 sets and a mean intensity of 75-85% 1RM across the intervention. Strength and power training included the same exercises but repetition speed was faster in power groups.	Effect sizes and percentage increases demonstrated that the power group training with bands experienced substantially greater treatment effects with regards to power compared with other groups. In addition, effect sizes and percentage increases demonstrated a similar increase in strength between the strength group and power group training with bands.

demonstrates that chains can be combined with free-weight resistance to improve strength. In addition, it appears that including chains may provide additional advantages over a constant barbell resistance for certain biomechanical and physiological factors, including force related capabilities and the stress experienced at various joints. However, research is at present limited and the most effective combinations of acute and chronic variables to maximise strength increases when including chains are not known (A summary of intervention studies investigating the effects of resistance training with chains is included in table 1).

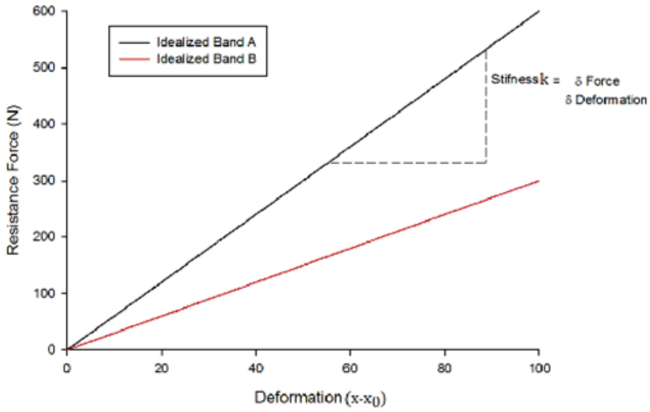
BAND RESISTANCE

Band resistances that are currently prescribed by exercise professionals to develop the strength of their clients are rubber-based. At present there are a number of manufacturers of bands and the mechanical properties depend upon the composition of the materials used [14]. The biomechanics associated with bands are slightly more complex than those encountered with chains. If we first consider an idealised resistance band, then it has a resting length below which no resistance is produced (i.e., it will be slack). As the band is stretched the amount of resistance generated is linearly related to the amount the band is stretched beyond its resting length (also referred to as the bands deformation). Different materials used in the production of bands can provide more or less resistance for the same amount of deformation. Figure 5, shows the force-deformation curve created by two idealised bands. Both curves are linear and illustrate that no resistance is generated when the deformation is equal to zero (i.e., both curves intercept the y-axis at the origin). We can see that band A produces double the resistance force of band B for the same amount of deformation. This means that the gradient of the force-deformation curve is twice as steep for band A compared with band B. The slope of the force-deformation curve is referred to as the stiffness of the band and represents how much resistance is provided for a given amount of deformation. We can summarise the properties that determine the resistance provided by bands in the following equation

$$F=-k(x-x_0) \qquad (2)$$

Where (N) refers to *resistive force* produced by the band, (Nm^{-1}) is the stiffness of the band, (m) is the length of the band and (m) is the resting length of the band. Notice that the deformation of the band is equal to and that there is a minus sign to indicate that the resistive force created by the band acts to oppose its direction of stretch.

Figure 5 Force-deformation curves for two idealised bands



The stiffness of idealised band A is double that of idealised Band B. Thus for a given amount of deformation the resistance force is double for band A compared with B.

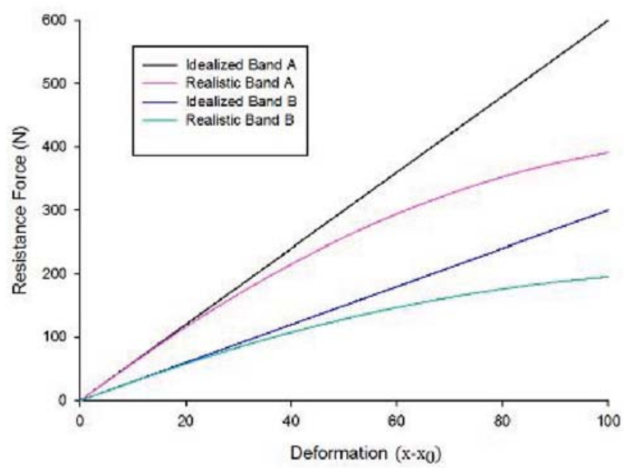
Similar to chains, a primary factor influencing the resistance provided by bands is the diameter of the material. In general, thicker bands are stiffer and provide more resistance for a given exercise (Figure 6). Also similar to chains, the resistance generated by an idealised band is linearly related to its displacement. However, more recent research has shown that in practice, bands provide a curvilinear force-deformation profile [14] (Figure 7). These results illustrate that resistance progressively increases with greater deformation. However, the slopes of the individual curves are not constant and generally become flatter with increased deformation.

One of the major differences between bands and

Figure 6 (Title): Standard bands used for resistance training

Legend: Bands are arranged in accordance to thickness, with thicker bands providing more resistance force.

Figure 7 (Title): Comparison of idealised and realistic force-deformation curves for resistance bands



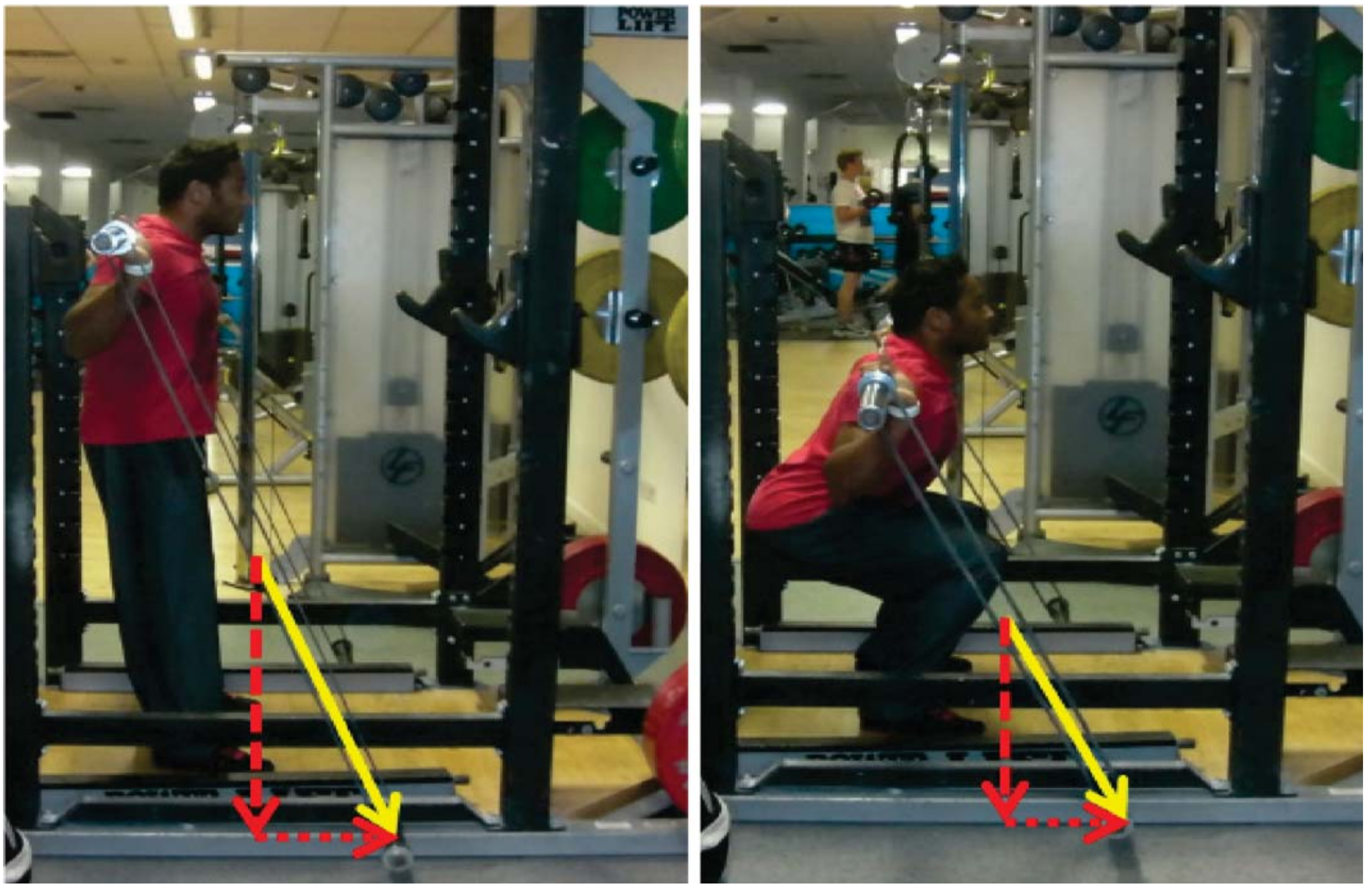
chains is that bands can be used to create substantial horizontal forces. For many of the exercises where bands are routinely included (e.g., squat, bench press, deadlift) the motion of the barbell is predominantly vertical and therefore excessive horizontal forces are unlikely to be warranted. Figure 8 shows how to set up bands to ensure the resistance force is vertical for the majority of the movement. It should be noted that this set-up will create substantial horizontal forces when the athlete attempts to un-rack the barbell and so care should be taken to counteract this horizontal force (see Figure 8). Importantly, there are instances where the exercise professional may wish to utilise the horizontal forces created with bands. For example, the exercise professional may wish to modify the squat technique of their client and minimise anterior displacement of the knee. With this technical change many individuals find it difficult to maintain their centre of mass (COM) over the base of support without substantial inclination of their trunk. Figure 9 shows how bands can be used to create a horizontal force that counteracts the rearward drift of the COM and maintains equilibrium whilst enabling the athlete to adopt an upright posture.

The research base investigating changes in strength from using bands is larger than that conducted from using chains. In untrained and novice athletes research has established that a range of band resistances can be used to generate significantly greater increases in strength compared to free weight training alone [15;16]. In addition, research incorporating higher level athletes has also demonstrated that resistance bands can be used to create increases in strength that are greater in magnitude to those realised with constant barbell resistance. Anderson *et al.* [17] conducted a 7 week training program with 44 Division I athletes performing upper- and lower-body resistance training sessions. Training programs for the athletes were identical except that one group performed the squat and bench press with constant barbell resistance whilst the other group used a combination of barbell resistance and bands. Three training sessions were scheduled each week with

Figure 8 (Title): Setting up bands for the squat exercise

Legend: Image on the left shows that a horizontal force is present when un-racking the barbell. This set-up is required to produce mainly vertical resistance forces during the actual squatting motion (images centre and right)

Figure 9 (Title): Alternative set-up for the squat exercise



Legend: Decomposition of the resistance force created by the bands illustrates the horizontal force that can be used to maintain balance as the body's centre of mass moves posteriorly.

upper- and lower-body sessions performed on an alternating basis. Sets (3-6), repetitions (2-10) and intensity (72-98% 1RM) were periodized in a wavelike progression during the 7 weeks. The combined resistance protocol used by half the participants during the squat and bench press was setup so that the resistance was 20% lower than the constant resistance at the bottom of the movement and 20% greater at the top. This setup ensured that the groups subsequently performed the same amount of work over the training period. Changes in strength over the 7 weeks were assessed using pre and post 1RM squat and bench press tests. The results from the study revealed that those athletes training with bands experienced significantly greater improvements in both the squat and bench press. Indeed, over the 7 weeks improvements in squat 1RM for those using bands was more than double that obtained by the group training with constant resistance (6% vs. 16% improvement). Similar results were reported for the squat and bench press recently by Joy *et al.* [11]. However, in this study those performing the exercises with bands lifted a load that was equal to the constant resistance at the bottom of the movement and increased to an extra 30% of the lifters maximum at the top of the movement. Whilst statistical tests were unable to differentiate between the improvements made by each group, percentage changes and effect sizes calculated for improvements in squat 1RM (20% vs. 27% improvement; effect size = 0.91 vs. 1.42) and bench press 1RM (3% vs. 8% improvement; effect size = 0.19 vs. 0.60) were both substantially higher for the group training with bands. The inability to differentiate between the groups despite strong evidence of a larger treatment effect when incorporating bands most likely reflects the small sample (14 total participants) recruited by Joy *et al.* [11]. Overall, the research on the use of bands is consistent and has demonstrated that strength improvements over the short term are equivalent or in most cases greater than those obtained with traditional constant barbell resistance. At present it is not clear if the stronger evidence base for bands compared with chains reflect a difference in the mechanical effects of the different materials, or is a function of more research being conducted with bands (A summary of intervention studies investigating the effects of resistance training with chains and bands is included in table 1).

DEVELOPMENT OF POWER

In part 2 of this review series [2] we discussed the main biomechanical differences between ballistic and non-ballistic resistance exercises. In particular, we noted that during non-ballistic resistance exercises (e.g., squat and bench press) the lifter must allow deceleration to occur to avoid projecting the body and/or load into the air. This requirement leads to lower force production during the latter stages of the concentric movement and potentially the need for antagonist muscles to assist in the process of deceleration. With lighter loads and higher movement velocities the need to decelerate during non-ballistic resistance exercise becomes more of an issue. In turn, this biomechanical feature may have important consequences for the development of muscular power, where the primary training method often involves performing exercises with the intent to lift sub-maximum loads as fast as possible. In the literature this training practice is commonly referred to as explosive resistance training (ERT) [18]. A number of researchers and exercise professionals have cautioned against using non-ballistic resistance exercises with ERT as the deceleration substantially reduces the amount of power produced and may also create muscle activation patterns that are not specific to actions performed in sports [19]. Instead, it is generally recommended that ERT is performed with ballistic resistance exercises such as the jump squat and bench throw. This is due to the fact that ballistic resistance exercises enable the lifter to accelerate throughout the entire concentric movement and therefore produce high power outputs and muscle activation patterns that are closer to those observed during common sporting actions [9; 19]. For example, when attempting to improve an athlete's ability to punch or explosively throw (e.g., chest pass in basketball), an exercise professional may prescribe the use of a bench press motion to provide adaptations that will transfer to the target movement. In a study conducted by Newton et al. [20] it was shown that if the barbell was projected into the air at the end of the bench press (i.e., the bench throw) using a load of 45% 1RM, peak power production was 67% greater than that achieved when performing the traditional bench press as fast as possible. In addition, positive acceleration could be maintained for the entire bench thrown motion (as also occurs during striking and throwing actions), whereas deceleration occurred after 60% of the traditional bench press movement [20].

It has been suggested that bands and chains can be used to alter the biomechanical stimulus associated with non-ballistic resistance exercises and as a result create a more suitable movement for ERT and the development of muscular power [21]. This suggestion is based on the theory that increasing resistance from unfurling chain mass and/or stretching of bands as the barbell is elevated will tend to cause the bar to decelerate unless the lifter continues greater force. If this greater force with bands or chains occurs at similar velocities to that observed with traditional loading, higher power outputs would also be developed. To test the theory using band resistance, Isratel *et al.* [22] tracked force, power and velocity values during the squat performed with constant resistance and with band resistance only. The results demonstrated that squats performed with bands produced significantly greater forces during the last 10% of the movement and significantly greater velocity and power values during the first and last sections of the movement compared with squats performed with a constant resistance. As expected the velocity and power values were greater during the initial stages of the movement performed with bands, as the total resistance was less than that obtained with the constant load. Importantly, velocity and power values were also larger when using bands during the final stages of the movement despite the fact that the total resistance was greater than that obtained with the constant load. This final result provides support for the theory that bands can be used to create an altered deceleration profile allowing the lifter to produce large forces for longer resulting in higher velocity and power outputs during the latter stages of the movement. Indeed, the authors of the study concluded that the inclusion of bands with the squat created a mechanical profile that was closer to that produced with a ballistic movement [22].

Contrasting results have been found for studies investigating whether the inclusion of chains can assist in decelerating the load whilst enabling the lifter to continue to produce force and higher power outputs for the majority of the movement. Swinton *et al.*[12] measured force, velocity and power during deadlifts performed with a constant resistance and with a combination of constant resistance and chains representing 20% and 40% of the lifters maximum. As expected, force production was higher at the end stages of the movement when performing deadlifts with chains as the total load was greater than that experienced with the constant resistance. However, the results also demonstrated that velocity and power were significantly lower for repetitions performed with chains for large sections of the movement. Figure 10 shows the velocity data from the study and we can see that very soon into the movement the velocity of the deadlifts performed with chains fell below that of the constant resistance despite the fact the overall mass lifted was less (i.e., the mass of the total resistance when using chains did not exceed the load of the constant resistance until the second half of the movement). The contrasting results obtained between bands and chains could have been caused by a number of factors. The chain resistances used by Swinton *et al.* [12] were very large and it is possible that different results may have been obtained if lower chain resistances or different chain and barbell load combinations were used. In addition, it is possible that the results obtained with the deadlift could have been influenced by the fact that there is no initial downwards movement, which serves to enhance the performance during the elevation phase. However, as discussed at the beginning of this article it is clear that mechanical differences exist between bands and chains, particularly when they are being incorporated with exercises performed at fast velocities. Importantly, bands

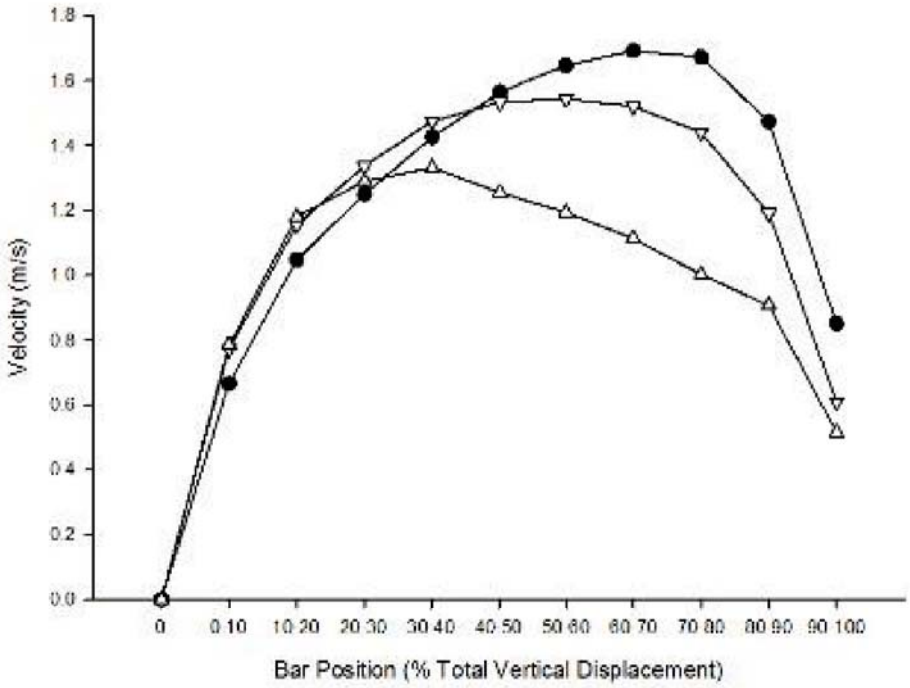


Figure 10 (Title): Velocity produced during deadlifts performed with a constant resistance and chains.

Legend: * Significant difference (p<0.05) between constant load and 20% 1RM chain for the corresponding segment of the movement. # Significant difference (p<0.05) between constant load and 40% 1RM chain for the corresponding segment of the movement. † Significant difference (p<0.05) between 20% 1RM chain and 40% 1RM chain for the corresponding segment of the movement. Taken from Swinton et al. (2011).[12]

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 the individual links are accelerated to the velocity of the barbell from initial stationary positions [9]. It is this latter point that in most circumstances will cause lower velocity and power outputs when using chains compared with bands and should be considered by exercise professionals considering including them in client resistance training programs.

Longitudinal studies that have investigated whether additional resistance material, in particular, bands can be used to improve the success of non-ballistic exercises with ERT have been informative. The majority of these studies have demonstrated that the inclusion of bands creates greater improvements in muscular power compared to ERT performed with non-ballistic exercises on their own. Using male and female college athletes with an average of 4 years resistance training experience, Anderson *et al.*[17] demonstrated that seven weeks training featuring the squat performed with bands resulted in improvements in average power (measured during a countermovement jump) that were approximately three times greater than those obtained from training without bands (24 W vs. 69 W improvement). In a slightly longer study conducted by Rhea *et al.*[23], male college athletes were randomly assigned to one of three groups. Each group performed the same lower-body resistance training program over 12 weeks, with the exception that group one performed the squat with a heavy load at a slow velocity, group two performed the squat with a light load and maximum velocity, and group three used the same protocol as group two with the addition of bands. Similar to the study conducted by Anderson *et al.*[17] changes in power were assessed by pre-post differences using the countermovement jump. The results of the study demonstrated a clear hierarchy with improvements in average power values of 5%, 11% and 18% for the slow movement, fast movement and fast movement with bands, respectively. The authors of the study concluded that the greater improvements in power obtained with the bands were due to the ability to create a stimulus that was closer to that created with ballistic movements [17]. The authors also reinforced the need to select a load that allows high velocities to be obtained and that the band and load combination provides a resistance profile that enables the lifter to attempt to accelerate the load for the majority of the movement [17]. Unfortunately, at present there is not enough research to determine the optimal exercise, load and band combinations. From the research that has been conducted, it appears that barbell loads of approximately 50% 1RM combined with band resistances of 20% 1RM (at the top of the movement) may be effective for developing muscular power when using exercises such as the squat, bench press and deadlift.

PRACTICAL APPLICATIONS

Collectively, the acute and intervention studies conducted on the inclusion of chains and bands in resistance training demonstrate that the practice offers the exercise professional a range of tools to enhance the strength and power of their clients. As is the case with many areas in exercise prescription, the vast number of possible acute and chronic training designs make it challenging to recommend a specific set of guidelines. Based on the results of acute biomechanical studies it is clear that the mechanical stimulus is unlikely to be altered and therefore have the potential to enhance the training response if very light chain or band resistances are used. Therefore, it is recommended that when using chains and bands, loads equivalent to at least 10% 1RM (at the top of the movement) are included, and in many cases when the individual is safely accustomed to the practice, loads of 20% 1RM or greater should be used. The primary exercises that should be selected when incorporating bands are those that feature ascending force-time curves such as the squat, bench press and deadlift. However, a number of their derivatives and closely associated movements including the front squat, lunge, incline press, shoulder press and Romainan deadlift should also be considered. The same exercises are also likely to benefit from the inclusion of chains; however, due to the vertical nature of the resistance provided with chains they may also be suitable to include with Olympic weightlifting exercises such as the clean, pulls and the jerk. It is important to note that many of the longitudinal studies conducted have attempted to equate the load lifted between the constant resistance exercises and those including chains and bands. Researchers have employed this design to minimise confounding effects from the amount of work performed, in attempts to isolate the effects due to varying resistance experienced when using chains and bands. However, in practical settings, chains and bands should be used to provide additional resistance thereby increasing the total load in regions where the individual has a greater capability to produce force. Therefore, when attempting to develop strength in particular, it is likely that the exercise professional should continue to prescribe similar loads and repetitions schemes but simply add an appropriate chain or band resistance. Taken from this perspective, the use of chains and bands are seen as a progression and therefore can be programmed in the more intense phases of a periodised program or used as a tool to stimulate adaptations when improvements begin to plateau. In contrast, when performing power training, the actual velocity of the movement may be very important and the exercise professional may have to use a more trial and error based approach whilst monitoring the velocity of the movement to ultimately create an appropriate training stimulus.

CONCLUSIONS

We hope that this series of articles has explained how an understanding of biomechanical principles is fundamental to best practice in resistance exercise prescription. In the first article we focused on moments and moment arms, explaining that these concepts provide the best insight into the stress experienced when performing resistance exercise and the basis upon which exercise professionals can modify the loading on a joint to maximise the potential for positive adaptations and minimise injury risk. In the second article we highlighted the importance of integrating biomechanical concepts within a larger neuromuscular framework. In particular, we discussed the importance of exercise selection when attempting to maximise power output and the transfer of adaptations to sports performance. In addition, we discussed the importance of factors such as the stretch shortening cycle and repetition velocity to produce adaptations that are specific to clients' goals. Finally, in this article we have demonstrated how the alternative resistance training practice of including bands and chains integrate many of the fundamental biomechanical and neuromechanical concepts previously discussed. Current research in the field of strength and conditioning has demonstrated that the inclusion of bands and chains may have the potential to improve the stimulus associated with traditional resistance training practices and provide superior adaptations. With a good understanding of biomechanical principles, the exercise professional should be able to select appropriate exercises and loads to combine with bands and chains to provide effective training that they can incorporate with their clients

REFERENCES

1. Keogh, J.W.L., Lake, J.P., & Swinton, P.A. (2013). Resistance training: Moments and moment arms. *Journal of Fitness Research, 2(2)*, 39-48.
2. Lake, J.P., Keogh, J.W.L., & Swinton, P.A. (In Press). Practical applications of biomechanical principles in resistance training: Neuromuscular factors and relationships. *Journal of Fitness Research*
3. Kulig, K., Andrews, J.G., & Hay, J.G. (1984). Human strength curves. *Exercise and Sport Sciences Reviews,* 12(1), 417-466.
4. Pearson, S.N., Cronin, J.B., Hume, P.A., & Slyfield, D. (2009). Kinematics and kinetics of the bench-press and bench-pull exercise in a strength-trained sporting population. *Sports Biomechanics*, 8(3), 245-254.
5. Foran, B. (1985). Advantages and disadvantages of isokinetics, variable resistance and free weights. *National Strength and Conditioning Association Journal, 7(1),* 24-25.
6. Harman, E. (1983). Resistive torque analysis of five Nautilus exercise machines. *Medicine and Science in Sports and Exercise, 7(3),* 248-261.
7. Hislop, H.J., & Perrine, J.J. (1967). The isokinetic concept of exercise. *Physical Therapy*, *47(2)*, 114-117.
8. Stone, M.H., Stone, M., & Sands, W.A. (2007). Principles and practice of resistance training. Champaign, Illinois: Human Kinetics.
9. Frost, D.M., Cronin, J., & Newton, R.U. (2010). A biomechanical evaluation of resistace: Fundamental concepts for training and sports performance. *Sports Medicine, 40(4),* 303-326.
10. Ghigiarelli, J.J., Nagle, E.F., Gross, F.L., Robertson, R.J., Irrgang, J.J., & Myslinski, T. (2009). The effects of a 7-week heavy elastic band and weight chain program on upper-body strength and upper-body power in a sample of Division 1-AA football players. *Journal of Strength and Conditioning Research, 23(3),* 756-764.
11. Joy, J.M., Lowery, R.P., de Souza, E.O., & Wilson, J.M. (2013). Elastic bands as a component of periodized resistance training. *Journal of Strength and Conditioning Research.* E-published ahead of print.
12. Swinton, P.A., Stewart, A.D., Keogh, J.W.L., Agouris, I., & Lloyd, R. (2011). Kinematic and kinetic analysis of maximal velocity deadlifts performed with and without the inclusion of chain resistance. *Journal of Strength and Conditioning Research, 25(11),* 3163-3174.
13. McCurdy, K., Langford, G., Ernest, J., Jenkerson, D., & Doscher, M. (2009). Comparison of chain- and plate-loaded bench press training on strength, joint pain, and muscle soreness in Division II baseball players. *Journal of Strength and Conditioning Research, 23(1),* 187-195.
14. McMaster, T.D., Cronin, J., & McGuigan, M.R. (2010). Quantification of rubber and chain-based resistance modes. *Journal of Strength and Conditioning Research, 24(8),* 2056-2064.
15. Heinecke, M., Jovick, B., Cooper, Z., & Wiechert, J. (2004). Comparison of strength gains in variable resistance bench press and isotonic bench press. *Journal of Strength and Conditioning Research, 18(4),* e361.

16. Bellar, D.M., Muller, M.D., Barkley, J.E., Kim, C.H., Ryan, E.J., et al. (2011). The effects of combined elastic- and free-weight tension vs. free-weight tension on one-repetition maximum strength in the bench press. *Journal of Strength and Conditioning Research, 25(2),* 459-463.
17. Anderson, C.E., Sforzo, G.A., & Sigg, J.A. (2008). The effects of combining elastic and free weight resistance on strength and power in athletes. *Journal of Strength and Conditioning Research, 22(2),* 567-574.
18. American College of Sports Medicine. (2009). Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise, 41(3),* 687-708.
19. Cormie, P., McGuigan, M.R., & Newton, R.U. (2011). Developing maximal neuromuscular power: Part 2. *Sports Medicine, 41(2),* 125-146.
20. Newton, R.U., Kraemer, W.J., Häkkinen, K., Humphries, B.J., & Murphy, A.J. (1996). Kinematics, kinetics and muscle activation during explosive upper body movements. *Journal of Applied Biomechanics,* 12(1), 31-43.
21. Baker, D.G., & Newton, R.U. (2009). Effect of kinetically altering a repetition via the use of chain resistance on velocity during the bench press. *Journal of Strength and Conditioning Research, 23(7),* 1941-1946.
22. Isratel, M.A., McBride, J.M., Nuzzo, J.L., Skinner, J.W., & Dayne, A.M. (2010). Kinetic and kinematic differences between squats performed with and without elastic bands. *Journal of Strength and Conditioning Research, 24(1),* 190-194.
23. Rhea, M.R., Kenn, J.G., & Dermody, B.M. (2009). Alterations in speed of squat movement and the use of accommodated resistance among college athletes training for power. *Journal of Strength and Conditioning Research, 23(9),* 2645-2650.
24. Ataee, J., Koozehchian, M.S., Kreider, R.B., & Zuo, L. (2014). Effectiveness of accommodation and constant resistance training on maximal strength and power in trained athletes. *PeerJ, 2,*e441.
25. Cronin, J., McNair, P.J., & Marshall, R.N. (2003). The effect of bungy weight training on muscle function and functional performance. *Journal of Sports Sciences, 21(1),* 59-71.