European Journal of Human Movement, 2014: **32**, 48-60

INTRA-REPETITION VARIABLE RESISTANCE TRAINING: PART 1-AN OVERVIEW

Ignacio J. Chirosa ; S. Baena ; Miguel Ángel Soria-Gila; Iker Javier Bautista ; Luís Javier Chirosa

CTS-642. Research and development on physical activity and sport. University of Granada

ABSTRACT

This series of reviews focuses on changes in external resistance during a repetition, and the ability to generate maximal muscular strength and power in a repetition. Part 1 focuses on the types and effects of Variable Resistance on neuromuscular adaptations. Part 2, which will follow in an upcoming edition of EJHM, explores the practical applications and methodological findings to the design of training programs that most effectively enhance maximal force production. The use of new strategies will help athletes and specialists improve performance, and will increase effectiveness of strength-training programs. The ability to generate maximal force is influenced by the time available to develop force, the magnitude of the external resistance, and the amount of resistance progressively added or reduced. This Part analyzes the most common ways of modifying external resistance using chains and elastic bands. These reviews discuss acute changes in the muscle environment and the impact that this has in maximal force production over different expressions of strength. Intra-Repetition Variable Resistance (irVR) training has been shown to impact different neuromuscular factors in many specific ways. Therefore, an understanding of the biological basis of maximal force production is essential for developing training programs that effectively enhance human strength capacity.

Key Words: intra-repetition, variable resistance, elastic bands, chains

RESUMEN

Esta serie de revisiones se centran en los cambios que provocan la resistencia variable (RV) durante una repetición, y la capacidad de generar la fuerza muscular máxima y la potencia durante la misma. La Parte 1 se centra en los tipos y efectos de la RV sobre diferentes adaptaciones neuromusculares. En la Parte 2, aparecerá en otra edición de la EJHM, explora las aplicaciones prácticas y hallazgos metodológicos para el diseño de programas de capacitación que mejoren de forma más efectiva la producción de fuerza máxima. El uso de nuevas estrategias ayudará a los atletas y especialistas a mejorar el rendimiento y aumentará la eficacia de los programas de entrenamiento de fuerza. La capacidad de generar fuerza máxima se ve influida por el tiempo disponible para desarrollar la fuerza, la magnitud de la resistencia externa (RE), así como la cantidad de resistencia añadida o reducida de forma variable. En esta parte se analizan las formas más comunes de modificación de la RE usando cadenas y bandas elásticas. Estas revisiones discuten los cambios agudos en el músculo y el impacto que esto tiene sobre la producción de fuerza máxima a través de las diferentes manifestaciones de la fuerza. Se ha demostrado que el impacto de diferentes factores neuromusculares en muchas formas específicas de RV intra-repetición. La comprensión de las bases biológicas de la producción de fuerza máxima es esencial para el desarrollo de programas que mejoran la eficacia de la capacidad producción de fuerza.

Palabras clave: intra-repetición, resistencia variable, bandas elásticas, cadenas

Correspondence:
Ignacio J. Chirosa Ríos.
Dpto. de Educación Física. Facultad de Ciencias del Deporte.
Universidad de Granada
Carretera de Alfacar s/n 18011. Granada (Spain)
ichirosa@ugr.es

Submitted: 15/06/2014
Accepted: 30/06/2014

INTRODUCTION

In a training process every moment counts. A split second can mean the difference between winning an Olympic medal or not. In order to apply the best stimulus it is necessary to join the largest number of structural training principles possible per unit of time. For this reason the concept of Intra-repetition Variable Resistance (irVR) is postulated as a new means to improve the responses of the neuromuscular system. The contexts in which an athlete performs, regardless of the level, change in space and time. Given these different scenarios, it is necessary to provide training stimuli that at least equal these mechanical-energy profiles.

In the scientific literature, the training methods that produce a progressive increase or decrease in the total weight of the load, both in concentric and eccentric phases of exercises are called Variable Resistance Exercises (VR). There are different strategies to modify the load during an exercise. This literature review focuses on those that change the resistance during repetition itself (encompassing both the concentric and eccentric phase) which are called Intra-repetition Variable Resistance exercises (irVR).

This strength training trend, like many others, is based on the principle of optimal stimulation intensity, and the concept of limited maximum efforts. When an athlete tries to develop different expressions of force, the muscles work at full capacity for a very small portion of time in a dynamic action (Frost, Cronin, & Newton, 2010). Behm & Sale, (1993) stated that one of the most important elements for improving the development of muscle strength is a mechanical impulse to accelerate a given load. Both ideas are implicit conditions to include in irVR training methods. This is the theoretical basis underpinning possible new hypotheses associated with irVR training and its positive effect on different strength expressions (Anderson, Sforzo, & Sigg, 2008).

To facilitate and optimize neuromuscular adaptations, the resistance must vary along each stage and type of muscle contraction (concentric contraction [CC], eccentric contraction [EC], isometric contraction [IC], stretch shortening cycle [SSC]). Therefore, load varies during the repetition itself (Cronin, McNair, & Marshall, 2003; Frost, Cronin, & Newton, 2010). This factor is characteristic of irVR, because in the concentric phase of the repetition the load will be progressively increased. Inversely, during the eccentric phase load will progressively decrease. The scientific evidence reviewed in this article seems sufficient to determine that this type of training provides a more rapid improvement in muscle strength, as compared to traditional training methods using only free weights (FW). Strength training that includes diverse stimuli, results in different neuromuscular adaptations in each muscle action, giving athletes greater wealth within their motor repertoire.

Terminological approach

In recent literature related to strength training the concept of Variable Resistance (VR) arises. Several VR methods are analyzed in this literature review, however it seems appropriate to clarify one aspect of nomenclature associated with them. Most authors who conduct research on VR use this name to refer to many aspects of the concept and this is not entirely accurate. The VR concept refers to a change of an established resistance or load of a repetition in a given exercise. Currently this concept is used to define a change in the resistance within a single repetition. This is not completely accurate, since there is no explicit mention of a load variation within the same repetition. This can lead to confusion as the load varies not only within the same repetition, but also at other times of training.

Therefore it is necessary to distinguish between sets and repetitions as the main parts of the design of resistance training programs. The total training load depends on many variables including the number of sets and repetitions, velocity, external resistance, the time between repetitions, and recovery time between sets (Bird, Tarpenning & Marino, 2005). The load will thus be modulated by repetitions and sets depending on the sort of material modified and the moment of the workout. As such, the point at which the resistance training will be varied must be determined. This distinction allows for two situations in which the load can be modulated (sets and repetitions). However, there are also two other times in which the load may be changed, and these are: between sets or repetitions, or within the same series or repetition. Thus, to use the concept of Variable Resistance only to refer to the variation of resistance within a single repetition, would be wrong and could lead to confusion about the lack of specificity.

There are four ways or times when external resistance can modulated and modified external resistance: a) Variable Resistance Between Reps (VRbr), when the resistance is changed between repetitions in the same set. b) Variable Resistance Between Sets (VRbs), when the resistance is changed between sets of a training session. c) Intra-set Variable Resistance (isVR), where resistance is modified within the series being done, d) Intra-repetition Variable Resistance (irVR), when a resistance change occurs within a single repetition (figure 1). The majority of authors refer to the concept of varying the resistance within the same repetition as RV. García-López, Herrero, Gonzalez-Calvo, Rhea, & Marin (2010) named this change of resistance in a different way calling it Intra-repetition or even calling it "in-set".

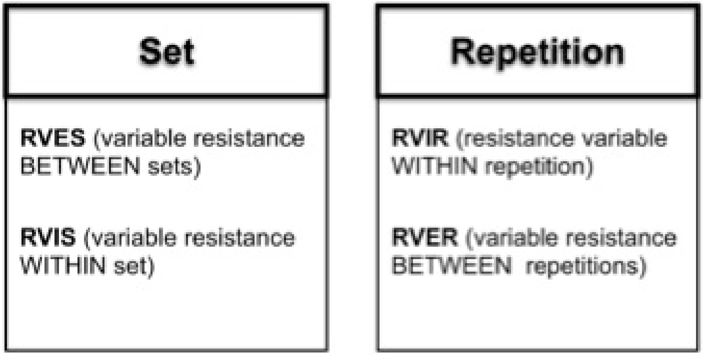

FIGURE 1: Types of variable resistance

Notice that, in this literature review, the focus has been on only one type of VR, that is irVR.

Types of intra-repetition variable resistance

There are many ways to modulate external resistance during a repetition; it depends on the material or accessory used. Most frequently studies found in the specific literature showed chains and elastic resistance (i.e. rubber bands) are generally used.Swinton, Lloyd, Agouris, & Stewart, (2009) performed a survey in 32 elite British powerlifters at an International competition, and the results showed that the use of irVR had become a common practice among athletes who lifted weights regularly. In this study 57% of the sample used chains, while the other 39% preferred using elastic bands to modify the load. The wide acceptance of these irVR techniques may be due to ease of transport, low cost, versatility and independence of gravity to perform the training, especially for elastic bands. McMaster, Cronin, & McGuigan (2009) reviewed common training methods, which fall within the concept of irVR methods, namely:

Lever and cams

The main feature of cams is their ability to consistently create resistance that matches muscular capacity that is being worked and keep it consistent in the entire range of motion (ROM) of an exercise. These training systems are suitable for beginners as they follow a fixed path of motion requiring less skill and less inter-muscular coordination (McMaster et al., 2009). The result is that it is likely to cause fewer injuries compared with other modes of training, since it is easier to maintain control of the load (Haff 2000; Harman 2000). The main function of this type of irVR seems destined mainly for therapeutic and rehabilitative use.

One of the biggest problems with cams and levers is that they cannot adapt to the user, and therefore the user needs to adapt to the possibilities offered by the cams and levers. McMaster et al., (2009) affirmed "a problem arises in the fact that the tool is designed for the average person and cannot accommodate people with extreme differences in anthropometry". Therefore, this type of resistance may not be beneficial as a specific method of sport training (Haff, 2009).

Elastic bands-Rubber based resistance (RBR)

The addition of elastic bands to FW training to convert it into an irVR method, is a clear example of how a load can be modulated linearly during a ROM. The resistance increases within the same repetition throughout the concentric phase and descends in the eccentric phase of a repetition. RBR use increases and decreases tension based on a product of curved shape deformation (McMaster et al., 2009). Due to the elastic characteristics of the RBR, several factors affect the amount of resistance supplied (McMaster et al., 2010; Palmer, McCurdy, Williams, & Walker, 2012). These include the density, the width, thickness, cross-sectional area, the resting length, and changes in the deformation of the corresponding band. If any of these variables of the material were to be altered, it is also likely to change in the tension-deformation relationship. With the wide variety of features intrinsic to the RBR, there are a mixture of variables and therefore increased difficulty when adapting to the personal/individual characteristics of the users (McMaster et al, 2009, 2010; Palmer et al., 2012). For this reason it is necessary to know deformation and thus the resistance produced by elastic. Thus the tension supplied to the exercise can be easily predicted based on equations that have been developed (Shoepe, Ramirez, & Almstedt, 2010). Other research, Shoepe et al., (2010) established regression equations and corresponding resistance values for all bands, establishing fixed patterns for the bench press and squats using elastic bands. These investigations (McMaster et al, 2010; Shoepe et al, 2010) offset, to some extent, the problems of establishing a protocol adapting the tension provided by the RBR to the personal characteristics of each individual.

Chains

The use of irVR including chains is becoming increasingly popular in high performance training though it is not a common form of training (Coker, Berning, & Briggs, 2006; Simmons, 1999). The big difference in using chains versus elastic bands is that the external resistance describes a linear function.

In other words, that is because the same weight is always added, progressively through the ROM by each link in the chain. The properties of chains and elastic bands are based on the same system of load augmentation as the load increases in the concentric phase and decreases in the eccentric phase. The biggest difference between the two methods is that the chains offer linear resistance (the load increases and decreases steadily) while with RBR this increase and decrease in load occurs in an exponential function.

The RBR are dependent on the "tension-deformation" relationship, while the resistance chain depends on the vertical displacement and the gravitational force. Also, the use of chains allows addition of free weights to the chain in the form of links and thus varies the pattern of the load (external resistance) and the neuromuscular stimulus provoked (McMaster et al., 2009). Therefore training is special when elastic bands or chains are combined with FW, as different types of training involve singular physiological effects. But despite the profile and differences between chains and RBR, the scientific literature reflects similar results between one method and another. A physiological difference was found only in one study (Rhea, Kenn, & Dermody, 2009); in this case muscle is capable of storing elastic potential energy during the eccentric phase of the lift and then release this energy in the form of kinetic energy during the concentric phase of lifting (Hostler et al., 2001).

Effects of irVR resistance on different strength parameters

To improve training efficiency, new methods are continually evolving. In recent years, the method of irVR has gained wide acceptance as part of workout routines. Theories of irVR training argue that these methods produce greater neuromuscular activation, increased fatigue and consequently greater muscle demand, thereby producing a greater improvement in strength and power than could be achieved through traditional workouts using only free weights. This type of training is performed not only to develop muscle strength, but there is also scientific evidence of the benefits of irVR in physical therapy and rehabilitation. The method provides greater ROM through a muscle strengthening and controlled stretching (Dobbs, 2010; Patterson, Stegink Jansen, Hogan & Nassif, 2001; Wallace, Winchester, & McGuigan, 2006).

A study developed by Anderson et al., (2008) evaluated a sample of 44 athletes for seven weeks. The objective was to assess the improvement in force production in the bench press and squat. Mean power output and body composition were measured. There were two training groups with the experimental group using irVR (free weights plus elastic bands) and the control group using traditional FW. Results showed a significant improvement in the experimental group over the control one of nearly three times greater for squat

(16.47 ± 5.67 vs 6.84 ± 4.42 kg), twice as high for the bench press (6.68 ± 3.41 vs 3.34 ± 2.67 kg), and almost three times for mean power (68.55 ± 84.35W vs 23.66 ± 40.56W.)

Bellar et al., (2011) performed a similar study with untrained subjects for thirteen weeks. In this case, only the improvement in 1RM was measured between the control group (FW) and the experimental group, who used FW plus elastic bands (irVR). Again the experimental group obtained significant improvements as compared to the control group (irVR = 9.95 ± 3.7 kg vs FW = 7.56 ± 2.8 kg). Meanwhile, Baker & Newton, (2009), analyzed thirteen professional rugby players, measuring mean and maximum velocity in the concentric phase, when executing a bench press at 75% of the 1RM for 2 sets of 3 repetitions. In this case the experimental group used FW in addition to chains, as compared to the control group that only used FW. Results showed a 10% increase in mean and maximum velocity in the experimental group over the control group, thereby justifying the use of chains in explosive heavy loads workouts.

Wallace et al., (2006) through a cross-sectional study with semi-trained subjects in the squat, compared possible improvements in maximum strength, peak power and strength development throughout the concentric phase of the movement. This evaluation compared FW and irVR (rubber bands) with different load percentages. The squat was performed in 2 sets of 3 repetitions on two non-consecutive days. Significant differences were found in both peak power and peak maximum force, which improved under certain irVR percentages (20% irVR + 80% FW). However, there were no significant improvements when working with the same load but different modulations of external resistance (35% irVR + 65% FW).

Aboodarda, George, Mokhtar, & Thompson, (2011) compared the effect of 10 RM performed with Nautilus Machine and irVR training on indicators of muscle damage; maximum voluntary force production, the rate of muscle soreness (DOMS), the concentration of creatine kinase in the plasma (CK), and increased muscle CSA in magnetic resonance. The results showed significantly higher average forces applied in the Nautilus Machines as compared to irVR group (362 ± 34.2N vs 266.73 ± 44.6N, respectively). However, indicators of muscle damage (DOMS and CK) had a very similar response in both training modes. These results suggest that both forms of training provide similar external resistance, although in the irVR method a lower external force was needed.

Colado & Triplett, (2008) compared the effect of the irVR training method and workout with weight machines on body composition and functional capacity in healthy sedentary middle-aged women. The results concluded that irVR training leads to similar physiological responses compared to those obtained using traditional weight training machines in the first phase of training.

García-López et al., (2010) conducted a study in which an elastic resistance (ER) was applied to a bicep curl machine to compare the number of repetitions, perceived exertion (RPE) and kinematic parameters at 70% of 1RM. They established a control group where the biceps curl exercise was applied without ER. Although there were no significant differences in relation to the intra-repetition kinematics, the ER group tended to reduce the peak acceleration of the load. Distributing a more uniform external resistance throughout the ROM, caused increased fatigue, which could explain why the ER group obtained a lower number of repetitions. The authors concluded that this type of work would be more favorable for users who want an improvement in muscle hypertrophy.

Another study carried out by Prejean, Cronin & Lawrence (2011) investigated acute effects on power in the bench press. Two sessions were held prior to the measurement of 3 sets x 5 reps at 85% of 1RM in bench press. The only difference is that one session was carried out with only FW and the other with the irVR method, combining resistance bands and FW with a 15% variable load and an 85% fixed load. There were 72 hours between the two training sessions and at the end of each session power production was assessed with 50% of 1RM. The difference between the two assessments was only 1 watt in the case of the irVR session, while the difference between the free weight session was 46 watts. Therefore, this research showed a greater improvement of acute power in the irVR group compared to the FW group.

Cronin et al, (2003) conducted two studies related to irVR methods. The first analyzed the electromyographic characteristics (EMG) and kinematics of three different techniques: "traditional squat, non-bungy jump squat and bungy jump squat." The second study examined training with and without the inclusion of a rubber band in a deep squat jump, to determine how it affected muscle function, multidirectional agility, capacity and performance of the single jump with one leg. The two experimental groups performed 10 weeks of training with ballistic weights. The kinematic and EMG data of the bungee and non-bungee squat technique differ significantly from those of the traditional squat in all measured variables. The only difference between bungee and non-bungee squatting position was increased EMG during activity the latter stages (70-100%) of the phase. However, training with elastic bands and free weights resulted in a significant improvement in the performance (21.5%) compared with the other groups.

The study by Jakubiak & Saunders, (2008) aimed to optimize the transfer of irVR training methods to a specific technical movement in Taekwondo. Twelve Taekwondo professionals trained with elastic resistance for 4 weeks. The sample was divided into two groups of six; a control group that performed regular taekwondo training and an experimental group who trained for the technical gesture using elastic bands. The results showed significant improvement between groups: a 7% increase in the speed of impact, in the experimental group while there was no improvement in the control group.

From the point of view of physical rehabilitation, a study by McCurdy, Langford, Ernest, Jenkerson, & Doscher, (2009) obtained interesting results. This study compared possible improvements in strength and perception of shoulder pain in the shoulder in two groups of professional baseball players. The first group trained using chains attached to free weights and the other trained with the traditional method of FW. Maximum force (1RM) was evaluated at the beginning and at the end of 9 weeks of training. The results showed no significant improvements in strength between groups. However, despite producing a similar improvement in strength, three times the incidence of shoulder pain was reported in the FW group (average total of 2.15 vs 6.14). However a similar level of pain was reported (9.38 vs 10.57) for the irVR and FW groups respectively.

Ghigiarelli et al., (2009) evaluated the effect of seven weeks of training on the execution velocity with 1 RM and 5 RM. Thirty-six semi-professional footballers were divided into 3 groups of 12 each. They conducted similar training routines. The three groups were 1) elastic resistance attached to FW (ER), 2) chains attached to FW (CFW) and finally 3) traditional training FW (Control). The results showed improvements in the irVR groups, although they were not significant enough EB (848-883 W) and CFW (856-878 W) versus control (918-928 W).

It is important to address the velocity of execution in any exercise as different velocities imply different actions (Pereira & Gomes, 2003). Under this premise, Rhea et al., (2009) evaluated the effect of heavy, slow movements in irVR training on peak power and strength development in the jump ability. 48 athletes completed a 12-week training program in which the sample was divided into 3 groups with similar training characteristic except for velocity. The groups were slow (S), fast (F), and fast, plus irVR using elastic bands (FVR). Pre-post testing of maximum strength and jumping power were performed. Data revealed a significant difference between improvements in power between the slow and FVR groups ($p = 0.02$). The FVR treatment group demonstrated a much greater effect size (ES) (17.8%, SE = 1.06) than the Fast group (11.0%, SE = 0.80) and a greater adaptation than the slow group (4.8%, ES = 0.28). This suggests that irVR training with elastic bands at a fast rate appears to offer greater performance advantages with respect to the maximum force and peak power developed with a slow endurance exercise.

Shoepe, Ramirez, Rovetti, Kohler, & Almstedt (2011) investigated the effects of traditional free weight training (FW) and irVR method in two training groups for 24 weeks. The workout routines were similar but used a variable 20-35% load percentage, provided by elastic bands. The subjects were evaluated in 1RM for squat and bench press while strength and power were assessed by isokinetic dynamometry. The results show how the mean power for the squat 1RM was significantly higher after training in the irVR group as compared with the control ($p < 0.05$). However, the FW group also showed significant improvements in 1RM for bench press. Thus, no significant differences between groups irVR and FW and were found. The author concludes that the key lies in the combination of irVR and FW exercises to increase strength and power in this particular sample (men and untrained college women).

Stevenson, Warpeha, Dietz, Giveans, & Erdman, (2010) evaluated the differences between a FW and elastic band (irVR) squat. Peak and mean velocity in the eccentric and concentric phases (PV-I, PV-C, E-MV, MV-C), peak force (PF), and peak power in the concentric phase and the RFD were measured immediately before and after the movement could even been perceived. The evaluation was performed using 3 sets of 3 reps of squats (55% maximum repeat [1RM]) on 2 separate days: one day without bands and the other using bands in random order. The rate used by the variable resistance was 20% of the 1RM. Results showed that PV-E and RFD were significantly higher ($p < 0.05$) using irVR while PV-C and C-MV were higher with FW. There were no differences in other variables.

CONCLUSIONS

Intra-repetition Variable Resistance training methods are increasingly accepted in strength training. In the scientific literature about strength training methods the results of irVR are clear. Traditionally, these methods have relied on the use of chains and elastic bands, although these are not the only methods that cause a resistance change in the same repetition. Other tools used in this training method include tires, cams or eccentric pulleys. However, the literature concerning strength training with irVR almost exclusively refers to chains and elastic bands.

The reasons behind these finds are still unclear. More research is needed to understand the phenomenon completely, although the evidence shows that muscle working at full capacity for a very small portion of time in a dynamic repetition leads to greater results than achieved with traditional free weights.

Therefore, throughout a repetition where the load is progressively varying in intensity there is more stimuli. In addition to this aspect, one of the most important factors that enhances the development of strength, among others, are the physical efforts required to accelerate a load. If force is trained in different ways, each different form of training creates a distinct and specific neuromuscular adaptation for such training. In relation to the muscular action, it has been shown that to facilitate maximum neuromuscular participation resistance should be varied along all stages of muscle contraction. To achieve this, the load itself should change, congruent with the factors found in irVR methods.

References

Aboodarda, S. J., George, J., Mokhtar, A. H., & Thompson, M. (2011). Muscle strength and damage following two modes of variable resistance training. *Journal of Sports Science and Medicine, 10*(4), 635-642.

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.

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.

Behm, D., & Sale, D. (1993). Velocity specificity of resistance training. *Sports Medicine, 15*(6), 374-388.

Bellar, D. M., Muller, M. D., Barkley, J. E., Kim, C., Ida, K., Ryan, E. J., & Glickman, E. L. (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.

Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing resistance training programmes to enhance muscular fitness: a review of the acute programme variables. *Sports Medicine, 35*(10), 841–851.

Coker, C. A., Berning, J. M., & Briggs, D. L. (2006). A preliminary investigation of the biomechanical and perceptual influence of chain resistance on the performance of the snatch. *Journal of Strength and Conditioning Research, 20*(4), 887-891.

Colado, J. C., Garcia-Masso, X., Triplett, T. N., Flandez, J., Borreani, S., & Tella, V. (2012). Concurrent validation of the omni-resistance exercise scale of perceived exertion with thera-band resistance bands. *Journal of Strength and Conditioning Research, 26*(11), 3018-3024.

Cronin, J., McNair, P., & Marshall, R. (2003). The effects of bungy weight training on muscle function and functional performance. *Journal of Sports Sciences, 21*(1), 59-71.

Dobbs, C. W. (2010). *Effect of variable resistance training on lower limb strength and power development: A training study*.

Frost, D. M., Cronin, J., & Newton, R. U. (2010). A biomechanical evaluation of resistance fundamental concepts for training and sports performance. *Sports Medicine, 40*(4), 303-326.

Garcia-Lopez, D., Herrero, A. J., Gonzalez-Calvo, G., Rhea, M. R., & Marin, P. J. (2010). Influence of "in series'' elastic resistance on muscular performance during a biceps-curl set on the cable machine. *Journal of Strength and Conditioning Research, 24*(9), 2449-2455.

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.

Haff, G. G. (2000). Roundtable discussion: Machines versus free weights. *Strength and Conditioning Journal, 22*(6), 18-30.

Harman E. (2000). *Biomechanics of resistance exercise*. In: Essentials of Strength Training and Conditioning (2nd ed.). T. R. Baechle and R. W. Earle, eds. Champaign, IL Human Kinetics, 25–55.

Hostler, D., Schwirian, C. I., Campos, G., Toma, K., Crill, M. T., Hagerman, G. R., & Staron, R. S. (2001). Skeletal muscle adaptations in elastic resistance-trained young men and women. *European Journal of Applied Physiology,* 86(2), 112-118.

Jakubiak, N., & Saunders, D. H. (2008). The feasibility and efficacy of elastic resistance training for improving the velocity of the olympic taekwondo turning kick. *Journal of Strength and Conditioning Research, 22*(4), 1194-1197.

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.

McCurdy, K., Langford, G., Jenkerson, D., & Doscher, M. (2008). The validity and reliability of the 1rm bench press using chain-loaded resistance. *Journal of Strength and Conditioning Research, 22*(3), 678-683.

McMaster, D. T., Cronin, J., & McGuigan, M. (2009). Forms of variable resistance training. *Strength and Conditioning Journal, 31*(1), 50-64.

McMaster, D. T., Cronin, J., & McGuigan, M. R. (2010). Quantification of rubber and chain-based resistance modes. *Journal of Strength and Conditioning Research, 24*(8), 2056-2064.

Newton, R. U., Murphy, A. J., Humphries, B. J., Wilson, G. J., Kraemer, W. J., & Hakkinen, K. (1997). Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European Journal of Applied Physiology and Occupational Physiology, 75*(4), 333-342.

Palmer, T. B., McCurdy, K. W., Williams, J. S., & Walker, J. L. (2012). Electromyographic analysis of the biceps femoris during conventional and rubber-based band squats. *Medicine and Science in Sports and Exercise, 44*, 625-625.

Patterson, R. M., Jansen, C. W. S., Hogan, H. A., & Nassif, M. D. (2001). Material properties of thera-band tubing. Physical Therapy, 81(8), 1437-1445.

Pereira, M. I. R., & Gomes, P. S. C. (2003). Movement velocity in resistance training. *Sports medicine, 33*(6), 427–438.

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.

Shoepe, T. C., Ramirez, D. A., & Almstedt, H. C. (2010). Elastic band prediction equations for combined free-weight and elastic band bench presses and squats. *Journal of Strength and Conditioning Research, 24*(1), 195-200.

Shoepe, T. C., Ramirez, D. A., Rovetti, R. J., Kohler, D. R., & Almstedt, H. C. (2011). The effects of 24 weeks of resistance training with simultaneous elastic and free weight loading on muscular performance of novice lifters. *Journal of Human Kinetics, 29*, 93-106.

Simmons LP (1999). Bands and chains. Pow USA 22: 26–27.

Stevenson, M. W., Warpeha, J. M., Dietz, C. C., Giveans, R. M., & Erdman, A. G. (2010). Acute effects of elastic bands during the free-weight barbell back squat exercise on velocity, power, and force production. *Journal of Strength and Conditioning Research, 24*(11), 2944-2954.

Swinton, P. A., Lloyd, R., Agouris, I., & Stewart, A. (2009). Contemporary training practices in elite british powerlifters: Survey results from an international competition. *Journal of Strength and Conditioning Research, 23*(2), 380-384.

Wallace, B. J., Winchester, J. B., & McGuigan, M. R. (2006). Effects of elastic bands on force and power characteristics during the back squat exercise. *Journal of Strength and Conditioning Research, 20*(2), 268-272.