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Effects of Elastic Bands on Force and Power Characteristics During the Back Squat Exercise

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ABSTRACT. Wallace, B.J., J.B. Winchester, and M.R. McGuigan. Effects of elastic bands on force and power characteristics during the back squat exercise. *J. Strength Cond. Res. 20(2):268–272. 2006.*—Athletes commonly use elastic bands as a training method to increase strength and performance. The purpose of this study was to investigate the effect of elastic bands on peak force (PF), peak power (PP), and peak rate of force development (RFD) during the back-squat exercise (BSE). Ten recreationally resistance-trained subjects (4 women, 6 men, mean age 21.3 ± 1.5 years) were tested for their 1 repetition maximum (1RM) in the BSE (mean 117.6 ± 48.2 kg) on a Smith machine. Testing was performed on 2 separate days, with 2 sets of 3 repetitions being performed for each condition. Testing was conducted at 60% and 85% of 1RM with and without using elastic bands. In addition, 2 elastic band loading conditions were tested (B1 and B2) at each of the 2 resistances. No bands (NB) represents where all of the resistance was acquired from free-weights. B1 represents where approximately 80% of the resistance was provided by free-weights, and approximately 20% was provided by bands. B2 represents where approximately 65% of the resistance was provided by free-weights, and approximately 35% was provided from bands. The subjects completed the BSE under each condition, whereas PF, PP, and RFD was recorded using a force platform. There was a significant ($p < 0.05$) increase in PF between NB-85 and B2-85 of 16%. Between B1-85 and B2-85, PF was increased significantly by 5% ($p < 0.05$). There was a significant ($p < 0.05$) increase in PP between NB-85 and B2-85 of 24%. No significant differences were observed in RFD during the 85% conditions or for any of the measured variables during the 60% conditions ($p < 0.05$). The results suggest that the use of elastic bands in conjunction with free weights can significantly increase PF and PP during the BSE over free-weight resistance alone under certain loading conditions. The greatest differences are observed during the higher loading conditions, with the B1-85 condition appearing to be optimal for athletic performance of the ones we tested. The strength training professional could use variable resistance training (VRT) to increase PF and PP more than the traditional BSE can. VRT could also be used to train these 2 performance characteristics together, which might be especially useful in season, when weight-room training volume can sometimes be limited.

KEY WORDS. variable resistance, resistance training, strength, biomechanics

Introduction

Athletes and recreational lifters are continually looking for new methods that will be helpful in improving performance and strength. The back-squat exercise (BSE) is regarded as one of the best exercises for achieving these goals (7). One newer method of squatting that is being used is variable resistance training (VRT). One way to perform this type of training is to attach elastic bands to a loaded barbell to combine elastic and weight-plate resistance (22). Historically, elastic bands have been used for rehabilitation (23) or sport-specific purposes such as swinging a tennis racquet (4, 25). Recently, however, these same principles have been modified and applied to structural strength and power movements in an effort to induce greater gains (22).

One of the limitations of traditional resistance exercise (TRE) is the large deceleration period at the end of the concentric motion (12, 18). A type of training called "ballistic training" has been prescribed to help solve this problem. Ballistic training occurs when the lifter attempts to accelerate the barbell throughout an unlimited range of motion, which usually results in either a jumping motion or the release of the barbell from the hands (21). Examples of such lifts are the jump squat and bench press throw. This type of training has been shown to be effective in improving the functional performance of athletes (17). However, high loads are not typically used with this type of training. Use of VRT is an attempt to combine the range of motion and acceleration benefits of ballistic training while allowing higher loads normally used in TRE.

Theoretically, VRT allows a lifter to optimally load muscles throughout the range of motion by using the mechanical advantage of muscles (2, 10). Mechanical advantage is largely a product of the length–tension relationship of skeletal muscle (11). VRT is believed to take advantage of this length–tension relationship by allowing for increased muscle activation through the concentric portion of the BSE (19). VRT also increases force during the later phases of the eccentric portion of the lift (8). This would be expected because the added tension toward the end of the concentric phase requires increased force to finish the lift; and extra force is required toward the end of the eccentric phase to slow the barbell because of the added band tension in addition to the weight plates pulling the barbell downward in the early phases of the eccentric phase.

Although there is anecdotal evidence that VRT does provide strength and power benefits greater than TRE, there is little scientific evidence to support this claim. To our knowledge, no previous studies have measured objective performance variables under different loading conditions when using bands as a moderate or high percentage of the overall load for any exercise. It was hypothesized that peak force (PF) would be increased with VRT vs. TRE under the heavier repetition maximum (RM) conditions, whereas peak power (PP) and peak rate of force development (RFD) would be increased under the lighter RM conditions. Further, it was hypothesized that greater increases would be observed in the conditions that received a greater percentage of the overall resistance from the bands. The purpose of this study was to investigate the acute effects of elastic bands on PF, PP, and RFD in the BSE under different loading conditions.

Methods

Experimental Approach to the Problem

In this cross-sectional study, we investigated the kinetic properties of these elastic bands (BNS Band system, Power-Up USA, Inc, Milwaukee, WI) over a range of different displacements and loading conditions. The initial portion of the study was designed to assess the reliability of the force output of the bands and to compare their kinetic properties with the reported force properties from the manufacturer. The second part of the study compared the PF, PP, and RFD of the BSE, performed with and without elastic bands.

Subjects

Four recreationally resistance-trained women (age 20.8 ± 1.0 years; height 149.1 ± 5.8 cm; mass 70.1 ± 8.5 kg) and 6 men (age 21.7 ± 1.8 years; height 155.1 ± 6.0 cm; mass 94.8 ± 18.8 kg) volunteered to be subjects in this study. All subjects had at least 6 months of training in the BSE before their participation. All subjects read and signed an institution-approved informed-consent form before participating in the study. Approval for the use of human subjects was obtained from the institution per their requirements before any subjects were tested.

Study One

In this first part of the study, we determined the kinetic properties of the elastic bands. The bands were anchored at different lengths and placed on either side of a Quattro Jump Force Plate (Kistler Instrument Corporation, Amherst, NY). One pair of matching bands was anchored to both the Smith machine frame and bar. The "heavy" (blue) and "light" (red) bands were each stretched and isometrically held during separate occasions at 4 different lengths (61.0, 68.6, 78.7, and 88.9 cm) by an individual standing on the force plate.

The resting length of the bands and the results of the 4 trials are presented in Table 1. The fourth length is a measure near the stretch limit of the bands, beyond the level that any subject stretched the bands to while standing upright. The force plate was zeroed before each trial, with the individual standing on it while holding the unloaded barbell, so only the force provided by the bands was measured during the trials. Three trials were performed at each length, and ground reaction force was calculated. The resistance values of band lengths not directly tested were interpolated based on the tested values and the linear force-producing properties of the material used to manufacture the bands.

Table 1. Length-tension data compared with manufacturer's reported force output; no significant differences between actual mean force and manufacturer's reported mean force for any of the lengths measured.

Band length	Mean force (n)	Manufacturer reported force (n)	Coefficient of variation
Blue 38.1 cm	0.00	0.00	0.00
Blue 61.0 cm	138.17	200.17	0.47
Blue 68.6 cm	234.95	266.89	2.57
Blue 78.7 cm	304.67	355.86	2.37
Blue 88.9 cm	373.33	444.83	1.74
Red 38.1 cm	0.00	0.00	0.00
Red 61.0 cm	71.29	133.45	3.22
Red 68.6 cm	146.89	177.93	3.54
Red 78.7 cm	218.00	235.76	3.64
Red 88.9 cm	292.67	298.03	3.23

Study Two

Preliminary Testing Procedures

On the first of 3 days of testing each of the 10 subjects performed a 1RM test on the Smith machine BSE. Previously described methods were used to determine 1RM strength (9). Subjects were required to warm-up for 10 repetitions at 50% of their predicted 1RM weight, 5 repetitions at 70%, 3 repetitions at 80%, and 1 repetition at 90%. Subjects then conducted up to 3 single-repetition sets to determine their actual 1RM. Three minutes were given between warm-up sets, and 5 minutes were given between 1RM attempts. The depth of each 1RM attempt was controlled so that the tops of the subject's thighs were parallel with the floor. After each subject's 1RM was determined, weight-plate resistance was reduced, and bands were attached to both sides of the barbell for a familiarization period. Each subject performed several sets of squats with the bands attached to the barbell.

Primary Testing Procedures

Subjects warmed-up on a stationary bicycle for 3 minutes before testing began. Three-minute rest periods were given between sets of the same condition, and 5 minutes rest was given between sets of different conditions. Squat depth was set for each subject such that the tops of their quadriceps were parallel with the floor. Subjects were instructed to exert their PF against the barbell during the entire concentric portion of each repetition (5). Subjects performed 2 sets of 3 repetitions for each of the day's 3 conditions. Testing was conducted on day 2 at 60% of 1RM (20), and on day 3 at 85% of 1RM (3). Subjects had at least 48 hours between testing sessions. On both days testing was conducted with and without using elastic bands.

One TRE- and 2 VRT-loading conditions were tested (in the order of no bands (NB), and B1 and B2, respectively) at each of the 2 RM resistances. No bands represents all of the resistance being acquired from free-weights, B1 represents 20% of the total resistance being acquired from bands, and B2 represents 35% being acquired from bands. Force, power, and time were recorded for the duration of each set using the force platform. RFD was found by calculating the slope of the force-time graph during the concentric portion of the lift. Peak values for each set were calculated from these records.

The elastic band conditions were normalized to the

NB condition using the following method: (a) the desired resistance for the subject was calculated (60% or 85% 1RM) and loaded onto the bar using weight-plates; (b) the desired value of resistance to come from the bands for the given condition was determined (equal to 20% or 35%); (c) half of the value from step b was taken off of the free-weight loaded bar; and (d) the bands were set up to provide the resistance value when the subject was standing erect with the bar on their shoulders, calculated in step b.

It was important in each VRT condition to subtract half of the band's resistance from the barbell's free-weight mass so that the band conditions did not have a higher average resistance value than the NB conditions. Adding the total value to come from bands to the barbell when the subject was standing erect made sure that the loading from the bands was not greater than what was desired for the given condition. If the subject was not standing erect when the bands were added, the bands would stretch when that person did stand erect, resulting in too high a load from the bands. Normalizing the resistance in this fashion assured that the average total resistance for the band conditions for each percentage of 1RM, upon 1 full repetition of the squat, was equal to the average resistance provided by the TRE condition. This occurs because the bands increase tension during the concentric phase and decrease tension during the eccentric phase of the BSE.

Equipment

The elastic bands were set up as to progressively increase overall resistance during the concentric portion of each repetition. Conversely, they progressively decreased overall resistance through the eccentric portion of each repetition. The bands were set up so that, at the end of the eccentric motion, there was still slight tension on them. If the bands were allowed to slack in the bottom position of the squat, they could have caused an uninvited force spike, when the subject started the concentric motion. The Quattro Jump software recorded the force and power characteristics measured during each set. The recording frequency was set at 500 Hz.

Statistical Analyses

Values are reported as mean (± *SD*). Reliability of the elastic bands was assessed using coefficient of variation (CV). The results of the force produced for the bands were compared using a 1-way repeated-measures analysis of variance (ANOVA) with Tukey post hoc comparisons. Linear regression analyses for both the red and blue bands were also calculated.

A 2-way (load × band) repeated-measures ANOVA was used to compare PF, PP, and RFD. For all testing conditions, the level of significance was set at $p \leq 0.05$.

Results

Study One

The force–length characteristics of the bands are shown in Table 1. The CVs indicate that the force characteristics of the bands were very reliable (CV < 3.7%). The R-value between measured forces for the blue bands was 0.99, and for the red bands, it was 0.98. The force values obtained from our analysis were not significantly different from the manufacturer's reported values.

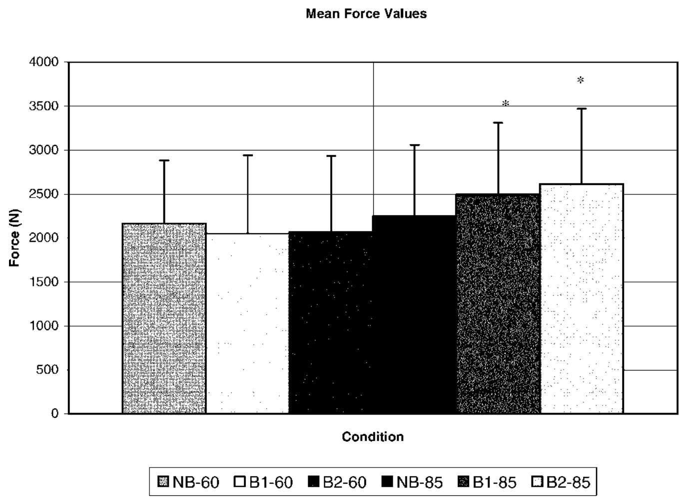

Figure 1. Mean force values for each condition.
* Significantly greater mean force values for B1-85 and B2-85 conditions compared with NB-85 condition ($p < 0.05$). NB-60 = no bands at 60% 1 repetition maximum (1RM); B1-60 = 20% band resistance at 60% 1RM; B2-60 = 35% band resistance at 85% 1RM; NB-85 = no bands at 85% 1RM; B1-85 = 20% band resistance at 85% 1RM, B2-85 = 35% band resistance at 85% of 1RM.

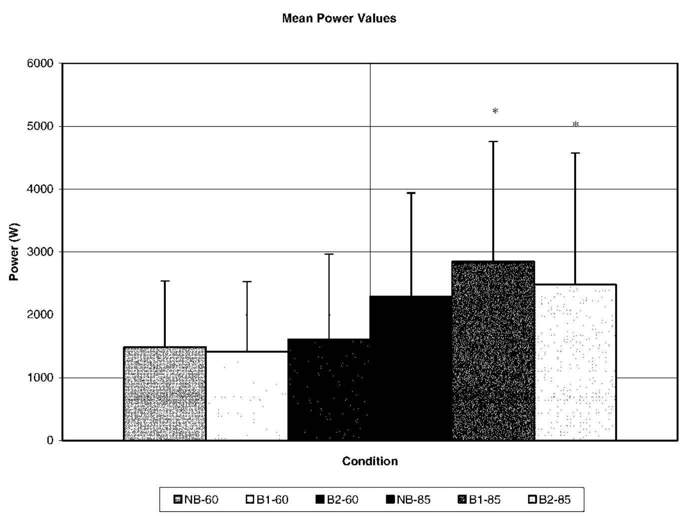

Figure 2. Mean power values for each condition.
* Significantly greater mean power values for B1-85 and B2-85 conditions compared with NB-85 condition ($p < 0.05$). NB-60 = no bands at 60% 1 repetition maximum (1RM); B1-60 = 20% band resistance at 60% 1RM; B2-60 = 35% band resistance at 85% 1RM; NB-85 = no bands at 85% 1RM; B1-85 = 20% band resistance at 85% 1RM, B2-85 = 35% band resistance at 85% of 1RM.

Study Two

The PF, PP, and RFD readings for each of the 6 conditions are shown in Figures 1–3. The data analyses showed that there was no significant ($p < 0.05$) difference in PF or PP between any of the 60% conditions. RFD was increased between NB-60 and B2-60 and between NB-85 and B2-85, but neither increase was statistically significant ($p < 0.05$). There were significant differences between the 85% conditions in PF and PP ($p < 0.05$). PF was increased by 16% between the NB-85 and B2-85 con-

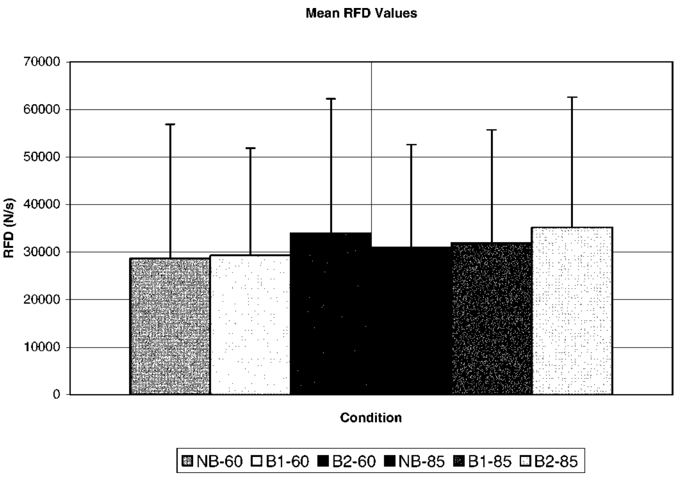

FIGURE 3. Mean peak rate of force development (RFD) values for each condition. No significant differences observed. NB-60 = no bands at 60% 1 repetition maximum (1RM); B1-60 = 20% band resistance at 60% 1RM; B2-60 = 35% band resistance at 85% 1RM; NB-85 = no bands at 85% 1RM; B1-85 = 20% band resistance at 85% 1RM; B2-85 = 35% band resistance at 85% of 1RM.

ditions. There was also a significant difference of 5% in PF between B1-85 and B2-85 ($p < 0.05$). PP was significantly increased by 24% between NB-85 and B1-85 ($p < 0.05$). Between B1-85 and B2-85 there was a significant decrease of 13% in PP ($p < 0.05$).

DISCUSSION

From this study, we observed significant increases in PF and PP with VRT compared with TRE. However, there is equivocal information available regarding the effectiveness of elastic bands in training (1, 8, 10, 13, 14, 16, 19; J. Claxton, unpublished report). In one study that looked at using just elastic band resistance compared with TRE, free weights seemed to be superior in generating favorable musculoskeletal adaptations (14). In addition, elastic bands alone have been shown to significantly improve strength when compared with aerobic and control groups (16). The results of VRT, in most cases, seem superior to the results achieved from TRE for strength, force, power, velocity, lean body mass, and electromyographic (EMG) activity (1, 8 13, 19; J. Claxton, unpublished report); however, not all studies have come to this conclusion for each measure (8, 10, 19).

Strength and power are the 2 measures that seem to be most improved by the proper use of VRT (1, 13, 19; J. Claxton, unpublished report), even if all uses do not provide significant benefits (8, 10). The trend seems to be that significant increases in strength, force, and power measures are not seen in studies in which only a small percentage of the overall load was achieved from elastic bands (8, 10) but are seen in studies that achieved a larger percentage of the overall load from bands (1, 13, 19; J. Claxton, unpublished report). However, our results indicate that there may be a ceiling for the amount of resistance that can come from bands before a decline in performance measures is observed.

The exact mode of neurological and musculoskeletal adaptations of VRT compared with TRE is not completely understood, but a basic understanding of the phenomenon does exist. It has been said that mechanical advantage is achieved by the use of elastic bands (2, 10). Mechanical advantage is largely dependent on the length–tension relationship of skeletal muscle (11, 21). Because muscles can produce their PF at or near the length that they normally maintain in the body because of thick and thin filament cross-bridging (11), PF should be generated in the concentric portion of the BSE, when the lifter is at or near full extension. Considering this relationship and that a resistance must be used that the activated muscles can handle in their overall weakest position for full range of motion to occur, the primary movers involved in the BSE are not optimally loaded during much of the repetition in TRE (4).

VRT increases tension progressively throughout the concentric portion of the BSE and decreases tension progressively throughout the eccentric portion. The increasing concentric tension shortens the deceleration phase in TRE (J. Claxton, unpublished report), which is the least-beneficial portion, and can be as much as 51.7% of the concentric phase at 81% 1RM (12). Using VRT overloads the activated muscles through a full range of motion (4), allowing the muscles to produce PF when they are best able to (2, 10), using the mechanical advantage properties of skeletal muscle. In addition, a possible by-product of shortening the deceleration phase is a lengthening of the amount of time near peak velocity (J. Claxton, unpublished report), which could increase RFD over time (25).

Increased eccentric loading also occurs with the use of elastic bands (8). Eccentric loading has been shown to be associated with higher force values than concentric loading (15). Greater velocity is achieved near the beginning of the eccentric phase with increased loading, and research has shown that greater force is necessary to slow the barbell during the final portions of the eccentric phase, when velocity is increased (6). It has been hypothesized that because of this, VRT may be an effective way to increase strength and athletic performance (8).

The most common way to calculate the amount of resistance coming from bands is to set them up so that the combined VRT resistance, after the lifter has achieved full extension, is equal to the resistance that would otherwise come from just free weights in TRE. This method does not properly normalize the VRT conditions to the TRE condition because the overall average resistance for any given repetition is less, which may take away from the validity of the method.

Of the several types of bands available on the consumer market, most will work for resistance training. When making a determination as to the type of bands to use, it is important to consider whether there is an accurate way to quantify the exact resistance that would be received at a given length. Although we found no significant differences between the measured and reported manufacturer values for the bands used in this study, the CVs do indicate some variation in the force values of these bands. Knowing the resistance received from the bands helps ensure the validity of the loading for the exercise to be performed. In addition, to reduce the risk of injury, it is critical that the bands used be securely anchored to the barbell and frame of the piece of lifting equipment to be used. Lifters should be aware of the different feeling that adding bands provides throughout the entirety of the repetition (10). It is also important to note that bands can strongly pull the barbell in the direction of their force vector during the unracking process until the barbell is centered directly above that vector because this can have a "slingshot" effect on lifters if they and their spotters are not cautious. This safety consideration is of particular importance if the barbell is not on a guided path, such as in a Smith machine.

Possible limitations of VRT may be the cost of equipment and the additional time necessary for setup and removal of the bands themselves. A further consideration could be time and effort needed to calculate the appropriate resistances and ratios of band vs. free-weight resistance (10). Although cost may be a prohibitive, most forms of bands are uncomplicated and take little additional time for setup when compared with TRE. Additionally, calculating band resistances for a given workout, using the method mentioned in this article, takes a minimal amount of time once the procedure is fully understood.

PRACTICAL APPLICATIONS

The results of this study suggest that the use of VRT can allow for significant increases in both PF and PP in the BSE when compared with TRE at a given 1RM resistance. Of the conditions tested, power athletes may benefit most from using the B1-85 condition because PP declines significantly between that condition and the B2-85 condition, whereas PF is not dramatically different. It is worth noting that advanced athletes may respond differently to VRT than the subjects in this study did.

These results could be helpful in training athletes who could benefit from increased PF and PP. VRT could be used as a separate training modality during various parts of a training cycle as a way to facilitate greater strength and power increases over TRE. This form of training could be used during in-season programs as a way to improve PF and PP at the same time, without having to train them during separate microcycles or mesocycles. These increases could translate into improvements in vertical jump and ballistic performance (19). In addition, VRT could allow the strength and conditioning professional greater flexibility in exercise prescription with respect to exercise variety.

Additional studies measuring PF, PP, velocity, and EMG activity in VRT during the final stages of the concentric and eccentric portions of the BSE could be useful in determining the specific modes of musculoskeletal adaptations involved. Further studies should also focus on the long-term effectiveness of VRT compared with TRE for strength and power exercises.

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