
COMPARISON BETWEEN THE EFFECTS OF COMBINING ELASTIC AND FREE-WEIGHT RESISTANCE AND FREE-WEIGHT RESISTANCE ON FORCE AND POWER PRODUCTION

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ABSTRACT

Paditsaeree, K, Intiraporn, C, and Lawsirirat, C. Comparison between the effects of combining elastic and free-weight resistance and free-weight resistance on force and power production. *J Strength Cond Res* 30(10): 2713–2722, 2016—Elastic tubing attached to a barbell has been reported to enhance strength and power to a greater extent as compared with conventional barbells. The aim of this study was to investigate the effect of the additional elastic tubing to a barbell during a clean pull on peak power (PP), peak velocity (PV), and peak force (PF). Six competitive female weightlifters (mean age, 16.7 ± 2.1 years) performed 3 sets of 3 repetitions of the clean pull at 90% of 1 repetition maximum (1RM). Testing was conducted on 3 separate days: day 1 without elastic tubing (no tubing [NT]) and the other 2 days with 2 elastic tubing loading conditions (T10 and T20), in random order. No tubing represents a condition where all resistance was acquired from the barbell (90% of 1RM). T10 and T20 represent conditions of combining elastic tubing at 10 and 20% of the subjects' 90% 1RM with a barbell (90% of 1RM). One-way repeated-measures analysis of variance was used to assess loading conditions on PP, PV, and PF. The results showed that there was a significant increase in all variables—PP, PF, and PV—between T10 and NT and between T20 and NT ($p \leq 0.05$). The results revealed that adding a 10% increment to 90% of 1RM seems to be the optimal training condition for increasing power, force, and velocity during the clean pull.

KEY WORDS elastic tension, variable resistance, resistance training, peak force, peak power

INTRODUCTION

Muscular strength and power are extremely important for successful performance across many sports (4,17,20,31). Consequently, scientists and coaches focus on the development of many effective and efficient training programs that enable the improvement of these 2 abilities (7–9,16). One new method of training that is increasingly being used to enhance athletic ability and performance is variable resistance training (VRT) (27). The external resistive load changes throughout the range of motion in VRT; as a result, it can maximize the contracting muscles' force production throughout the range of motion (12). One variety of VRT is to attach elastic tubing to a barbell (3,10,15,18,24,30). This new training method requires elastic tubing to be attached to both ends of a barbell and anchored to the floor. The greatest external overload is provided by the barbell at the beginning or inner range of the concentric phase, whereas elastic tubing provides overload at the end or outer range of the concentric phase (21). As the tubing is stretched, greater resistance is applied. This possibly stimulates greater muscle activation or force generation.

Variable resistance training allows subjects to experience greater muscle activation and force generation because the load in VRT increases throughout the range of motion, which can compensate the reduction of the arm of moment between the fulcrum and the load. Let us consider the case when a subject is doing an arm curl exercise in traditional weightlifting. When the subject begins lifting the barbell, the distance between the barbell and the fulcrum is the farthest, thereby making the subject experience the heaviest load. However, as the subject lifts the barbell, the distance between the barbell and the fulcrum continues decreasing. The subject experiences lighter resistance load, even though the external resistance load is constant. In performing only weightlifting, although the subjects experience constant weight, muscle tension varies throughout a joint's range of motion. This is because the distance between the barbell and the fulcrum changes throughout the range of motion and so does the mechanical advantage of the muscle (13,14).

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TABLE 1. Characteristics of participants ($N = 6$).

Characteristics	$\bar{x} \pm SD$
Age (y)	16.7 ± 2.1
Body mass (kg)	63.3 ± 17.5
Body fat (%)	27.0 ± 6.1
Height (cm)	153.7 ± 6.2
Experience (y)	3.8 ± 1.7

Previous research (1,18,23,29) showed that the resistance provided by a barbell combined with elastic tubing could improve certain biomechanical variables, for example, muscular power and muscular strength in squat and bench press. Wallace et al. (29) showed that when subjects were tested with a combination of barbell and elastic tubing at 20 and 35% (B1 and B2), respectively, mean power and mean force of the subjects increased significantly compared with subjects who were tested with only a barbell. In their study, the researchers added 20 and 35% of 85% of subjects' 1 repetition maximum (1RM). In their study, the researchers added 20 and 35% of 85% of subjects' 1 repetition maximum (1RM). Several studies (5,6) have investigated the velocity of a barbell and vertical ground reaction force when subjects performed clean and snatch lift with chains added to the barbell. The results of these studies showed no significant differences between the bar's velocity and vertical ground reaction with the addition of chains to a barbell and the barbell alone. This may be because the proportion of loads from chains was small compared with the total resistant load, where the load from chains accounted for 5% of the total resistant load.

Even though VRT is widely studied, to the best of our knowledge, only a few studies focus on peak power (PP),

peak velocity (PV), and peak force (PF). In particular, our study focuses on augmenting VRT to training at 90% of 1RM because 90% of 1RM is considered very high intensity and often used in training weightlifters. To answer the question of whether a barbell alone or a barbell with elastic tubing is more effective for increasing force and power production in female competitive weightlifters during the clean pull, we attempted to investigate the effects of PP, PV, and PF during a clean pull when 10 and 20% of 90% of subjects' 1RM obtained from elastic tubing (T10 and T20, respectively) were added to 90% of subjects' 1RM.

We hypothesize that training using elastic tubing with a barbell during the clean pull would provide greater PP and PF when compared with training using a barbell alone. The addition of elastic tubing to a barbell increases the load for the subjects; thus, it requires that the subjects use more force to be able to do the clean pull (1,18,23,29). On the other hand, we also hypothesize that PV would be greater under the barbell-alone condition because under this condition, the resistance load is lightest and makes the subjects do the clean pull at the highest speed as compared with the other conditions. Furthermore, we hypothesize that PP and PF would be greater under T20 than under T10 because T20 provided a greater resistant load. Using the same argument, it was hypothesized that PV under T10 would be greater than PV under T20.

METHODS

Experimental Approach to the Problem

This study was designed to investigate the acute effect of PP, PV, and PF of the clean pull under 3 different conditions. In the first 2 conditions (i.e., T10 and T20) 10 and 20% of 90% of the subjects' 1RM is added to the barbell, which was set at 90% of subjects' 1RM. The additions of 10 and 20% were made by attaching elastic tubing to the barbell. Under the third condition, the subjects performed the clean pull only with the barbell, which was set at 90% of their 1RM.

In this research, the clean pull was examined instead of the full clean because the design of this study required the subjects to lift the barbell at a very high resistive loading; under such a condition, the subjects were likely to be injured from the full clean rather than the clean pull. This is because in the full clean, subjects need to perform a turnover of the clean where the elbows move around the bar; when elastic tubing is attached to the barbell, the subjects would have less time to perform the turnover of the clean, thereby resulting in a failed

TABLE 2. Mean $\pm$ SD values for each dependent variable and condition ($N = 6$).*

Dependent variable	Condition		
	NT	T10	T20
PP (W)	$2,193.62 \pm 739.61$	$2,439.98 \pm 862.36^\dagger$	$2,137.73 \pm 647.87$
PF (N)	$2,176.18 \pm 617.98$	$2,232.67 \pm 593.39^\dagger$	$2,246.43 \pm 606.43^\dagger$
PV ($m \cdot s^{-1}$)	$1.12 \pm 0.11^\S$	$1.17 \pm 0.15^\S$	1.03 ± 0.08

*NT = no tubing; T10 = additional 10% tubing combined with barbell; T20 = additional 20% tubing combined with barbell; PP = peak power; PF = peak force; PV = peak velocity.

† Significantly greater mean power value for the T10 condition compared with the NT and T20 conditions ($p \leq 0.05$).

‡ Significantly greater mean force values for the T10 and T20 conditions compared with the NT condition ($p \leq 0.05$).

§ Significantly greater mean velocity values for the T10 and NT conditions compared with the T20 condition ($p \leq 0.05$).

TABLE 3. Percentage changes and ES among the 3 testing conditions for each dependent variable.*

Dependent variable	Percentage change			ES		
	NT– T10	NT– T20	T10– T20	T10 and NT	T20 and NT	T20 and T10
PP (W)	11.23	–2.55	–12.39	0.31	–0.08	–0.40
PF (N)	2.60	3.23	0.62	0.09	0.11	0.02
PV ($\text{m}\cdot\text{s}^{-1}$)	4.39	–8.22	–12.08	0.37	–0.96	–1.22

*ES = effect size; NT = no tubing; T10 = additional 10% tubing combined with barbell; T20 = additional 20% tubing combined with barbell; PP = peak power; PF = peak force; PV = peak velocity.

attempt and possible injury. Moreover, the clean pull was used in this study because the second pull phase of the clean pull was found to produce the highest vertical ground reaction force and power output when compared with the first pull and the transition phase (25). From the mechanical perspective, greater vertical ground reaction forces would provide higher power output and greater vertical acceleration of the bar; thus, the performance of the clean would improve (11).

In the current study, subjects visited the laboratory on 4 separate days. Day 1 (the first day) involved explaining and conducting the consent process, explaining testing procedures, collecting biometric data, and estimating each subject's 1RM. The 3 experimental conditions (on days 2, 3, and 4) were executed a week after day 1. Monday, Wednesday, and Friday were chosen as days 2, 3, and 4, respectively, to ensure that subjects had adequate recovery time. Each subject performed 3 sets of 3 repetitions of the clean pull with a 3-minute rest between the sets to ensure adequate recovery of the phosphagen adenosine triphosphate (ATP) energy system (2).

Furthermore, 90% of 1RM was chosen because it is widely used in weightlifting training programs (11). The elastic tubing was set up in such a manner that at subjects' full extension or the finishing position of the clean pull, subjects would experience additional resistance load at 10 and 20% (T10 and T20, respectively) of 90% of their 1RM, which was provided by the barbell. The additional forces of 10 and 20% from the elastic tubing were chosen because these proportions fell

within the range of values used in previous research and represented a practical load exerted by the elastic tension (1,10,26,29).

Subjects

The sample group comprised 6 female competitive weightlifters (mean $\pm$ SD: age, 16.7 ± 2.1 years; weight, 63.6 ± 17.5 kg; height, 153.7 ± 6.2 cm; body fat, $27 \pm 6.1\%$) who are currently competing and have been competing for at least 2 years at the time of the study (mean experience, 3.8 ± 1.7 years). Descriptive data are reported in Table 1. Inclusion criteria were (a) at least 2 years of competitive experience, (b) aged between 15 and 20 years, and (c) no experience in training with a barbell combined with different types of elastic tension. Exclusion criteria included (a) no previous or current musculoskeletal injuries or (b) any other types of injury that could be worsened by performing the clean pull exercise.

Before beginning the experiments, informed consent was obtained from all subjects and the parents or guardians of subjects who were younger than 18 years. Ethics approval

TABLE 4. Correlation coefficient for the test-retest reliability among the 3 sets in each condition.*

Dependent variable	NT				T10				T20			
	Sets 1 and 2	Sets 1 and 3	Sets 2 and 3	Average	Sets 1 and 2	Sets 1 and 3	Sets 2 and 3	Average	Sets 1 and 2	Sets 1 and 3	Sets 2 and 3	Average
PP (W)	0.996	0.992	0.997	0.995	0.993	0.995	0.999	0.996	0.988	0.992	0.995	0.992
PF (N)	0.997	0.995	0.998	0.997	0.998	0.997	0.999	0.998	0.998	0.998	0.999	0.998
PV ($\text{m}\cdot\text{s}^{-1}$)	0.992	0.924	0.937	0.951	0.964	0.962	0.983	0.970	0.885	0.812	0.749	0.815
Overall correlation coefficient				0.981				0.988				0.935

*NT = no tubing; T10 = additional 10% tubing combined with barbell; T20 = additional 20% tubing combined with barbell; PP = peak power; PF = peak force; PV = peak velocity.

TABLE 5. Values of Pearson's product-moment correlation coefficient between the force of the first and second pulls of elastic tubing.

Days of testing	Colors and numbers of elastic tubing					
	Green no. 1 <i>r</i> (<i>p</i>)	Green no. 2 <i>r</i> (<i>p</i>)	Peach no. 1 <i>r</i> (<i>p</i>)	Peach no. 2 <i>r</i> (<i>p</i>)	Orange no. 1 <i>r</i> (<i>p</i>)	Orange no. 2 <i>r</i> (<i>p</i>)
Day 1	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.999 (0.000)	0.999 (0.000)	0.999 (0.000)
Day 2	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.999 (0.000)	1.000 (0.000)
Day 3	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.999 (0.000)	0.999 (0.000)

was granted by the Ethics Review Committee for Research Involving Human Research subjects, Health Science Group, Chulalongkorn University, Thailand.

Procedures

Preliminary Testing. After completing the informed consent process and providing explanations regarding testing procedures, subjects' biometric data were recorded. Weight, body fat, and height were recorded with a body composition analyzer (ioi 353; Jawon Medical, Kyungsan, South Korea). After the collection of biometric data, the subjects participated in a warm-up session before their 1RM of the clean pull was determined. The warm-up session included a general warm-up on an upright bicycle for 5 minutes at a workload of approximately 80 W. After the general warm-up phase, the subjects underwent a specific warm-up exercise that included several sets that followed progressive loading but decreasing the repetitions. After the subjects finished these warm-up exercises, the 1RM of the clean pull for each subject was determined under the supervision of their coach using the protocol established by Kraemer et al. (19).

After determining 1RM, 6 subjects were randomly divided into 3 groups (2 subjects per group) according to 3 types of resistance: (a) no tubing (NT), where all the resistance was acquired from the barbell (90% of 1RM); (b) T10, where 10% of 90% of the subjects' 1RM was added to the barbell (90% of 1RM); and (c) T20, where 20% of 90% subjects' 1RM was added to the barbell (90% of 1RM). Because this study focused on ascertaining the acute effect of the 3 resistance conditions, every subject needed to be tested for her PP, peak vertical ground reaction force, and PV in all 3 conditions. The order of the testing was determined using a Latin square design of 3×3 . Consequently, each group completed all 3 experimental conditions on 3 separate days, performing 1 condition per day.

Testing Procedures. Three experimental conditions (NT, T10, and T20) were executed the week after the preliminary testing. Monday, Wednesday, and Friday were chosen to ensure that the subjects had adequate recovery time. The subjects were instructed not to exercise heavily on the day before the tests, not to eat food for 2 hours, and not to drink caffeine-containing beverages for 4 hours before testing.

TABLE 6. Mean force of the first and second pulls of green elastic tubing on each testing day.

% elongation	Green no. 1			Green no. 2		
	Day 1 of testing $\bar{x}$ ($\bar{x} \pm 5\%$)	Day 2 of testing $\bar{x}$	Day 3 of testing $\bar{x}$	Day 1 of testing $\bar{x}$ ($\bar{x} \pm 5\%$)	Day 2 of testing $\bar{x}$	Day 3 of testing $\bar{x}$
50	3.225 (3.06–3.39)	3.195	3.220	3.195 (3.04–3.35)	3.215	3.190
100	4.945 (4.70–5.19)	4.925	4.940	4.900 (4.66–5.15)	4.885	4.930
150	6.310 (5.99–6.63)	6.295	6.285	6.355 (6.04–6.67)	6.330	6.320
200	7.940 (7.54–8.34)	7.925	7.925	7.935 (7.54–8.33)	7.975	7.960
250	9.530 (9.05–10.01)	9.520	9.495	9.635 (9.15–10.12)	9.695	9.655
300	11.405 (10.83–11.98)	11.395	11.370	11.525 (10.95–12.10)	11.515	11.540

TABLE 7. Mean force of the first and second pulls of peach elastic tubing on each testing day.

% elongation	Peach no. 1			Peach no. 2		
	Day 1 of testing	Day 2 of testing	Day 3 of testing	Day 1 of testing	Day 2 of testing	Day 3 of testing
	$\bar{x}$ ($\bar{x} \pm 5\%$)	$\bar{x}$	$\bar{x}$	$\bar{x}$ ($\bar{x} \pm 5\%$)	$\bar{x}$	$\bar{x}$
50	2.355 (2.24–2.47)	2.400	2.360	2.360 (2.24–2.48)	2.365	2.370
100	3.560 (3.38–3.74)	3.605	3.585	3.565 (3.39–3.74)	3.555	3.535
150	4.675 (4.44–4.91)	4.685	4.670	4.605 (4.37–4.84)	4.625	4.555
200	5.735 (5.45–6.02)	5.775	5.735	5.540 (5.26–5.82)	5.530	5.545
250	6.875 (6.53–7.22)	6.845	6.810	6.720 (6.38–7.06)	6.665	6.695
300	8.275 (7.86–8.69)	8.260	8.290	8.250 (7.84–8.66)	8.225	8.260

Moreover, they were instructed to sleep adequately before the test. Once the subjects visited the laboratory, they were weighed and then told to perform the general warm-up on the stationary bike, as previously described in the preliminary testing session. It should be noted that in the T10 and T20 conditions, the tension of the elastic tubing was determined before the general warm-up to confirm that the tension and condition of elastic tubing was consistent with other trials and that they were not damaged or deformed and also to confirm that the tensions provided by elastic tubes were equal to 10 or 20% of 90% of each subject's 1RM.

Furthermore, to eliminate the confounding factors of the test, we adopted a similar procedure from Stevenson et al. (26), where each subject was asked to do a squat jump (SJ) and underwent hand dynamometry (HD) tests after general warm-up to ensure that the neuromuscular status between each testing day was consistent (statistically similar, $p \geq 0.05$). After a general warm-up, 3 maximal consecutive SJs were performed on a force platform (Performance Plate; Fitness Technology, Adelaide, Australia), which was equipped with a computer software (Ballistic Measurement System; Innervations, Perth, Australia). The highest PP of the 3 consecutive jumps was recorded for each subject. To

eliminate the effects of arm swing, the subjects were asked to jump with their hands on their hips in all 3 jumps.

For the HD test, maximal isometric grip strength was measured using a handgrip dynamometer (Analogue A5001; Takei Scientific Instruments Co., Ltd., Tokyo, Japan). The subjects performed the handgrip task 3 times in each hand in an alternating format. The highest PF of each arm was recorded and summed up to yield the final recorded value. The values of the summed highest PF of each arm obtained from the HD test and the highest PP obtained from the SJ test were tested using a 1-way repeated-measures analysis of variance (ANOVA) to ensure that the neuromuscular status of each subject was statistically similar. In addition, it should be noted that each subject was weighed to ensure that there was no statistical difference among the 3 loading conditions.

After the general warm-up and neuromuscular testing, the subjects began their clean pull-specific warm-up comprising several sets, followed by a progressive loading with decreasing repetitions, until the final weight was 90% of their 1RM. It should be noted here that during the clean pull-specific warm-up, no elastic tubing was used, and this specific warm-up protocol was replicated for every laboratory visit. In this investigation, a certified powerlifting set (plates, bar, and

TABLE 8. Mean force of the first and second pulls of orange elastic tubing on each testing day.

% elongation	Orange no. 1			Orange no. 2		
	Day 1 of testing	Day 2 of testing	Day 3 of testing	Day 1 of testing	Day 2 of testing	Day 3 of testing
	$\bar{x}$ ($\bar{x} \pm 5\%$)	$\bar{x}$	$\bar{x}$	$\bar{x}$ ($\bar{x} \pm 5\%$)	$\bar{x}$	$\bar{x}$
50	1.405 (1.33–1.48)	1.400	1.420	1.425 (1.35–1.50)	1.405	1.355
100	2.185 (2.08–2.29)	2.185	2.115	2.155 (2.05–2.26)	2.140	2.185
150	2.735 (2.60–2.87)	2.725	2.725	2.815 (2.67–2.96)	2.800	2.735
200	3.490 (3.32–3.66)	3.405	3.455	3.520 (3.34–3.70)	3.490	3.490
250	4.255 (4.04–4.47)	4.215	4.215	4.275 (4.06–4.49)	4.270	4.255
300	5.290 (5.03–5.55)	5.190	5.085	5.135 (4.88–5.39)	5.255	5.290

TABLE 9. Mean $\pm$ SD values for SJ and HD tests on each testing day.*

Testing variables	Day 1 of testing	Day 2 of testing	Day 3 of testing
SJ	3,198.68 $\pm$ 532.21	3,141.37 $\pm$ 488.39	3,185.09 $\pm$ 516.44
HD	37.13 $\pm$ 3.38	36.50 $\pm$ 3.37	36.42 $\pm$ 3.19

*SJ = squat jumps; HD = hand dynamometry.

collars) in kilograms (Eleiko, Halmstad, Sweden) was used for all clean pulls.

After the clean pull-specific warm-up, the necessary equipment was set up. For the T10 and T20 conditions, elastic tubing of 3 different sizes and colors—orange, peach, and lime green (Sanctband; Sanctuary Health Sdn Bhd, Ipoh, Malaysia)—were chosen for use in combination with the barbell. Elastic tubes were hung from the ends of barbells in a symmetrical and equidistant manner, whereas the opposite ends were anchored to the floor with two 14-kg dumbbells (Figure 1).

In the T10 and T20 conditions, maximal tensions of the elastic tubing (10 and 20% of 90% of the 1RM, respectively) were provided at full extension or the finishing position of the clean pull, and the elastic tubing began to exert tension when the bar was at knee level. Because the original length of elastic tubing was too short when the bar was on the floor, the elastic tubing was set up to initially provide tension when the bar was at knee level. In addition, the resistance from 3 different sizes or colors of the elastic tubing was determined using the force plate to ensure that the elastic tubing could provide zero force and the prescribed force at knee level and at full extension of the clean pull, respectively. Moreover, the tension of the elastic tubing was calculated by taking the difference between the weight of the subject when she stood

on the force plate with only the empty bar and the weight of the subject when she stood still on the force plate with the bar attached to the elastic tubing at knee level and at full extension of the clean pull.

After the completion of the equipment setup, subjects performed 3 sets of 3 repetitions of the clean pull. A 3-minute rest

between sets was provided to ensure adequate recovery of the ATP energy system (2). Because the investigation (3) showed that power output decreased significantly after 3 repetitions in power exercises, 3 repetitions for each set were used in this study. The subjects were asked to perform each repetition as explosively as possible, and verbal encouragement was provided to ensure maximal effort throughout the testing performance.

Data Collection and Analysis

The clean pull was performed on a force platform (Performance Plate; Fitness Technology). In addition, a linear position transducer (IDM Instruments, Dandenong, Australia) was attached to the barbell. Both the force plate and linear position transducer were set to zero before each set, and the sampling frequency was set at 200 Hz using computer software (Ballistic Measurement System; Innervations). The vertical component of the PP output was obtained using the product of the bar velocity and the vertical ground reaction force. It must be noted that the PP output was obtained from the software, where the bar velocity was calculated using vertical displacement and time data after it was smoothed with a Butterworth fourth-order digital low-pass filter with a cutoff frequency of 16 Hz before differentiation using the finite difference technique. In addition, the PP values were recorded in the concentric phase of the clean pull.

The greatest values of PP, PF, and PV were taken from the 3 consecutive repetitions. Because the subjects performed 3 repetitions in 3 sets, these 3 greatest values were subsequently averaged to produce the final value for each subject in each condition. This method was used to exclude possible outliers because of poor repetitions and represented the best value of each condition.

Statistical Analyses

All statistical analyses were performed using SPSS statistical software for Windows (version 17.0; SPSS, Inc., Chicago, IL, USA). Values of each dependent variable and each condition are reported as mean ($\pm$ SD). Each of the dependent variables was analyzed with 1-way repeated-measures ANOVA with Least Significant Difference (LSD) post hoc comparisons to determine whether there were significant differences between each condition. The percentage changes were calculated between NT and T10 conditions, between NT and T20 conditions, and between T10 and T20 conditions. For

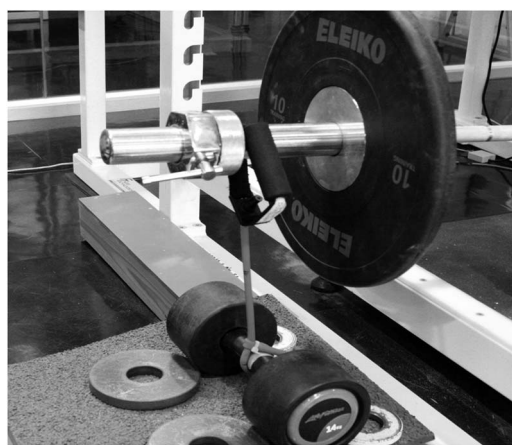


Figure 1. Setting up the elastic tubing in a barbell.

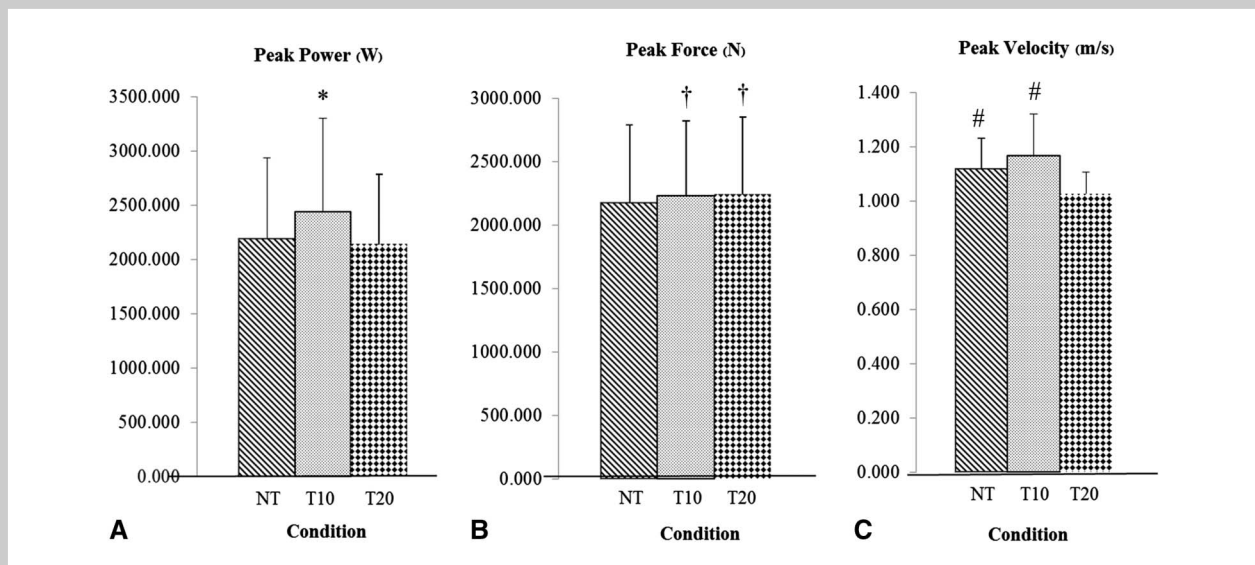


Figure 2. Graphical presentation of the results for each dependent variable: peak power (A), peak force (B), and peak velocity (C). *Significantly greater mean power values for the T10 condition compared with the NT and T20 conditions ($p \leq 0.05$). †Significantly greater mean force values for the T10 and T20 conditions compared with the NT condition ($p \leq 0.05$). #Significantly greater mean velocity values for the T10 and NT conditions compared with the T20 condition ($p \leq 0.05$). NT = no tubing.

example, the percentage change (between NT and T10 conditions) was calculated in the following manner: $(T10 - NT) \times 100/NT$. Effect sizes (ESs) between the 3 testing conditions for each dependent variable were calculated according to Cohen's d statistic. In addition, the criteria for interpreting the magnitude of the ES were <0.35 trivial, 0.35 – 0.8 small, 0.8 – 1.5 moderate, and >1.5 large (22). Values of biometric and neuromuscular status were also presented as mean ($\pm SD$). In addition, 1-way repeated-measures ANOVA was used to examine these data to ensure that the subjects were not statistically different for each of the testing conditions. It should also be noted that the level of significance was set at $p \leq 0.05$.

The reliability of the elastic tubing was assessed using Pearson's correlation to ensure that elastic tubing was always in the same or similar condition for all the tests. Before testing, the elastic tubing was pulled twice for the following percentages of elongation: 50, 100, 150, 200, 250, and 300%. These values of forces, which produced the percentage of elongation, were recorded and used to calculate the reliability of the elastic tubes. Moreover, the elastic tube would be changed to a new one if the reliability coefficient was <0.9 and if the average of the 2 values of forces producing each percentage of elongation differed from the force producing each percentage of elongation measured on day 1 by $\pm 5\%$.

RESULTS

The means and SD s for all variables investigated are presented in Table 2. Figures 2A–C graphically display the results for each dependent variable obtained from the 3 conditions. As shown in Table 2, the statistical analysis of PP

demonstrated significant differences between the T10 and NT conditions ($p = 0.015$) and between the T10 and T20 conditions ($p = 0.023$). Moreover, the percentage changes and ESs revealed a larger treatment effect in the T10 condition than in both the NT and T20 conditions (Table 3). However, no statistical differences were found between the T20 and NT conditions ($p \geq 0.05$).

With regard to PF, there were significant differences between the T20 and NT conditions and between the T10 and NT conditions, where the p values were 0.036 and 0.011, respectively. In addition, as shown in Table 3, the percentage changes and ESs demonstrated a greater treatment effect in both the T20 and T10 conditions than in the NT condition. However, no significant difference ($p \geq 0.05$) was observed between the T10 and T20 conditions.

With regard to PV, the statistical analysis also showed significant differences between the NT and T20 conditions ($p = 0.003$) and between the T10 and T20 conditions ($p = 0.01$). Furthermore, the percentage changes and ESs showed a greater treatment effect in both the NT and T10 conditions than in the T20 condition (Table 3). However, there was no significant difference ($p \geq 0.05$) between the T10 and NT conditions.

The correlation coefficients for the test-retest reliability of the 3 sets are reported in Table 4. For the NT, T10, and T20 conditions, the average overall coefficients were 0.981, 0.988, and 0.935, respectively. These results indicate that there was a high level of test-retest reliability, with the range of reliability being considered high when it is >0.9 (28).

To ensure that the elastic tubes were in similar condition in all the 3 conditions for each subject, the reliability

coefficient and mean values of forces producing percentage of elongation were reported, as described in the previous section. Pearson's correlation values, which demonstrated the correlations between 2 forces used to produce each percentage of elongation at 50, 100, 150, 200, 250, and 300%, are presented in Table 5. Because the reliability coefficients were >0.9 , it can be said that the level of test-retest reliability of the elastic tubes was high.

Moreover, the average of 2 force values from each percentage of elongation did not differ from the force producing each percentage of elongation obtained on day 1 of testing by $\pm 5\%$, as shown in Tables 6–8. Consequently, the elastic tubes remained unchanged in this study.

To ensure that the subjects entered the test with similar neuromuscular status, the results of the SJ and HD tests were reported, as shown in Table 9. The following are the average differences between days 1 and 2, between days 1 and 3, and between days 2 and 3: HD: 0.63 ± 0.29 , 0.71 ± 0.31 , and 0.08 ± 0.27 kg, respectively; SJ: 57.31 ± 39.16 , 13.59 ± 22.26 , and 43.73 ± 46.61 W, respectively; weight: 0.52 ± 0.25 , 0.25 ± 0.25 , and 0.27 ± 0.12 kg, respectively. In conclusion, we found no significant differences ($p \geq 0.05$) in the subjects' neuromuscular status (SJ, HD) or body weight data.

DISCUSSION

The purpose of this study was to investigate the effect of the addition of elastic tubing to a barbell in the concentric phase during the clean pull exercise on PP, PV, and PF. We will begin this discussion section with PF.

In this study, we hypothesized that adding elastic tubing to the barbell during the clean pull would provide greater PF when compared with a barbell alone. The results supported our hypothesis, where PF in the T20 and T10 conditions were significantly greater than that in the NT condition. Moreover, the results revealed that PF increased from NT to T10 (2.60%) and to T20 (3.23%). However, no statistically significant difference was observed between T20 and T10 conditions. As more force was exerted in T20 and T10 as compared with NT, the subjects needed to extend their legs more forcefully against the force platform. Consequently, the PFs in the T20 and T10 conditions were found to be statistically greater than the PF in the NT condition.

Our finding on PF is similar to the results of Wallace et al. (29) but contrasts with the results of Ebben and Jensen (10). This is because in the experimental design of Wallace et al. (29), the researchers added more resistant force to 85% of the subjects' 1RM, which was similar to the current study. However, instead of adding external force to the barbell, in the study by Ebben and Jensen (10), the loading conditions were controlled to be constant for (a) the weight plate alone, (b) the addition of chain to weight plate, and (c) the addition of elastic band to weight plate, thereby resulting in the same load for all 3 conditions. It is evident that the percentage changes in the current study (between NT and T20 conditions) and those in the study by Wallace et al. (29) (between

NB-85 and B2-85 conditions) were 3.23 and 16%, respectively.

Furthermore, it is possible that the reason for no statistical significance between T20 and T10 is because the distance of the clean pull lift, which is under the influence of elastic tubing, is small. In the clean pull lift, the subjects lifted the barbell from the ground and stopped when the barbell was at their hip. Although it began from the ground, the influence of the elastic tube began when the barbell was at the knee of the subjects. Consequently, the lifting distance under the influence of the elastic tube was from the knee to the hip of the subject, which was relatively small; thus, it did not affect the peak vertical ground reaction force when compared between the T10 and T20 conditions.

With regard to PV, it was significantly greater in the NT condition than in the T20 condition—PV decreased from NT to T20 (8.22%). Moreover, PV was also significantly greater in the T10 condition than in the T20 condition—PV increased from T20 to T10 (12.08%). These findings are in line with our hypothesis. The explanation for these findings is the additional load added to the barbell. Because the load was greater, the subjects were able to perform the clean pull at a lower speed. However, there was no statistical difference between the T10 and NT conditions. This is because the lifting distance under the influence of elastic tubes in the T10 condition was relatively small when compared with the NT condition. It should be noted that the findings in this study are in agreement with the results of Stevenson et al. (26), Berning et al. (5), and Coker et al. (6), in which a greater proportion of the external loads added to the barbell permitted the PV of the barbell to be slower than without the addition or addition of only a small proportion (5% in case of Berning et al. (5) and Coker et al. (6), and 10% in the case of this study) of external loads to the barbell. In the current study, the percentage changes revealed that PV decreased from NT to T20 (8.22%). Furthermore, the percentage changes in the studies by Stevenson et al. (26) (between the no-band and with-band conditions) and Berning et al. (5), in which the load was established at 85% of 1RM (between the no-chains and with-chains conditions), decreased to 3.76 and 2.99%, respectively. In the study by Coker et al. (6) (at 80% of 1RM), PV decreased by 4.23% from the no-chains condition to the with-chains condition.

As power is often a quantity in consideration, it was evident from the results of this study that PP in the T10 condition was statistically greater than that in the T20 and NT conditions. This is because under the T10 condition, the PF was greater than in the NT condition; however, no difference was found in PV for both the conditions. Meanwhile, PV in the T10 condition was greater than that in the T20 condition, but there was no difference between PF in both the conditions. Consequently, it can be said that T10 offers the optimum loading condition in this study because it yielded the maximum PP for the subjects in this study. In this study, PP increased from NT to T10 by 11.23%,

which is slightly similar to the results of Wallace et al. (29) (between NB-85 and B1-85 conditions) in which the percentage change between the 2 conditions was 24%.

In the present study, there was no statistical difference in PP between the T20 and NT conditions. This is because although T20 yielded significantly higher PF, it yielded slower PV than in the NT condition. Furthermore, because the difference in PF between the T20 and NT conditions is close to the difference in PV under the T20 and NT conditions, the PP, which is the product of PF and PV, is not statistically different between the 2 conditions. The results of this study related to PP were similar to those of Wallace et al. (29) and Stevenson et al. (26).

Furthermore, to confirm that the neuromuscular condition of the subjects was similar, 3 maximal consecutive SJ and HD tests, similar to those in a previous study (26), were conducted in the 3 testing days. It was reasonable to assume that these 2 screening tests performed before the clean pull would not significantly fatigue the subjects. Moreover, we ensured this by permitting subjects to rest for an adequate period. If the performance in these 2 tests before the clean pull showed significant differences between each testing day, it would have indicated that fatigue or some other factor has reduced the absolute maximal effort. However, if there was no significant difference in the performance in the 2 tests among the 3 testing days, it was reasonable to assume that the potential of maximal effort was similar.

Although this study has revealed an interesting aspect, it is not without any limitations. One obvious drawback of this study is the sample size and statistical power of this study. However, the focus of the current study was on weightlifting, which has relatively few practitioners. In this study, only female competitive weightlifters were included because we wanted to eliminate factors that may be influenced by gender. Therefore, it is possible that the statistical outcome of this study was affected by the sample size.

In summary, this study showed that adding 10 of 90% of subjects' 1RM (T10) to a barbell provided significantly greater PP than a barbell alone (NT) and adding 20 of 90% of subjects' 1RM (T20), although there was no statistical difference between the T20 and NT conditions. Hence, during the clean pull, the T10 condition provided an optimal proportion loading, which could increase power when compared with both the T20 and NT conditions. Moreover, the T10 condition could increase the vertical ground reaction force without sacrificing velocity when compared with the NT condition and also could improve velocity without sacrificing vertical ground reaction force when compared with the T20 condition, as shown in Table 2. However, if weightlifters are focused only on developing their strength, the T20 condition is recommended as an effective load.

Because this study is concerned with the acute effect of the 3 conditions, further research should investigate the effects of the combination of these 3 conditions in long-term training. In addition, untrained weightlifters, male competitive weightlifters,

and other sport athletes should be included in the sample. Furthermore, not only the clean pull but also jerk exercise should be investigated when adding elastic tension to evaluate the full movement of the clean and jerk.

PRACTICAL APPLICATIONS

The current research has demonstrated the acute effects of combined elastic tension and free-weight tension during the clean pull exercise in female competitive weightlifters. This study suggests that female weightlifters will benefit most when trained with the addition of 10 of 90% of their 1RM to a barbell because it will increase the PP of the subjects and improve speed and strength, as compared with training with a barbell alone. Consequently, increasing PP, particularly in the second pull phase, was found to produce the highest vertical ground reaction force and power output when compared with the first pull and transition phase (25); this could make athletes lift the bar faster and to the right height to have adequate time for performing the turnover of the clean, thereby resulting in a successful lift.

However, if weightlifters focus on improving only their strength, adding 20 of 90% of their 1RM to a barbell would provide a better result. Thus, choosing appropriate conditions is important for obtaining the potential benefits of combined elastic tension and free-weight tension for increasing power or force.

It should be noted that athletes who are not familiar with the addition of elastic tubing to a barbell should begin with light resistances of both elastic tubing and barbell; moreover, they should be supervised by a coach, particularly at the end of a motion when the resistance of elastic tubing is the greatest.

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