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Research article

Adding the Load Just Above Sticking Point Using Elastic Bands Optimizes Squat Performance, Perceived Effort Rate, and Cardiovascular Responses

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Abstract

Modifying basal elongation of elastic bands (EB) has been proven useful to increase some parameters of the intensity in variable resistance training. Therefore, the question arises as to whether the pertinent resistance could be applied with EB immediately above the sticking point in squat exercises to optimize the performance. The purpose was to analyze some variables of the external (kilograms and number of repetitions) and internal load (heart rate, blood pressure, and rate of perceived exertion) after six different conditions of the squat exercise when using weight plates (WP) or EB (placed at different points of the range of motion) and applying maximal or submaximal effort. Twenty physically active males (25.50 ± 5.26 yrs) underwent two sessions for familiarization and one for assessment. The six conditions (three with WP and three with EB) were randomly performed. The sticking point of each subject was measured using the knee joint angle and the resistance was applied with EB at this height. Immediately after finishing each set subjects reported perceived effort rate and cardiovascular measurements were taken. Repetitions completed, and kilograms used were recorded. Repeated measures testing evaluated differences between conditions. EB permitted performing 8 more repetitions compared to WP when the same load was added at standing position. Adding the load immediately above the sticking point significantly ($p < 0.05$) increased 24.7% the kilograms used and permitted participants to perform 3 more repetitions. Internal load measurements suggested that EB could significantly ($p < 0.05$) reduce the perceived effort rate and/or physiological stress depending on their application. EB are a suitable device to load the bar for squat exercises in fit young men. According to the necessities of the subjects, if the load with EB is added at different points of the range of motion, it could be possible to overcome the sticking point, to maximize the performance and/or modulate cardiovascular and perceptual responses.

Key words: Weightlifting, resistance training, variable resistance, heart rate, blood pressure, physical exertion.

Introduction

Elastic Bands (EB) are increasing in popularity for strength training for both health and physical performance (Colado et al., 2010; 2020; Colado and Triplett, 2008; Saeterbakken et al., 2014; Soria-Gila et al., 2015). EB have been shown to induce similar neuromuscular activation and adaptations to free weights and machines (Colado and Triplett, 2008; Colado et al., 2010; Sundstrup et al., 2012; Iversen et al., 2017), and provide optimal muscle stimulation across the entire range of motion for different resistance exercises such as the squat (Andersen et al., 2015; Saeterbakken et al., 2016; Joy et al., 2016).

The kilograms provided by EB in squat exercises decrease with decreasing knee angles, due to the elongation coefficient and regardless of gravity (Saeterbakken et al., 2016; Andersen et al., 2016). Through this part of the range of motion, the length of the bands is shorter, and thus, they add fewer kilograms to the exercise. Conversely, there is an increase in the kilograms with increasing knee angles (i.e. when the length of the bands is longer). This property of the EB may affect the outcomes when comparing EB to constant resistance devices. In one research aimed at comparing constant and variable resistances in squats at 6 repetitions maximum (RM) load, EB did not provide enough resistance to achieve the desired kilograms (Saeterbakken et al., 2016). Therefore, the authors needed to use weight plates (WP) in combination with the variable resistance to achieve the appropriate load. In this sense, Iversen et al. (2017) in their review reported lower muscle activation levels during the parts of the range of motion where the bands were relatively slack. These authors highlighted the necessity of using EB with considerable tension to reduce the differences in external loading with WP.

Different strategies have been proposed such as increasing the number of bands and pre-stretching the band to increase the kilograms provided by the EB (Treiber et al., 1998; Aboodarda et al., 2013; Page et al., 2015). The pre-stretch consists of incrementing the initial tension of the band, either augmenting the distance from the handle to the attachment (Treiber et al., 1998; Page et al., 2015) or shortening the initial length of the band (Aboodarda et al., 2013). Through these uses of the EB, authors obtained similar or even higher muscle activation levels (Aboodarda et al., 2013), improvements in functional performance for sports (Treiber et al., 1998; Page et al., 2015) and further strength gains (Treiber et al., 1998) than with constant resistance. However, the aforementioned strategies do not take into account the variability between the subject's characteristics such as height or execution form. In this context, Iversen et al. (2017) specified the limited opportunity for manipulating the amount of pre-stretch in exercises such as the squat where the height of the person may be a limiting factor. Under the light of this fact, the necessity arises of finding a method that considers the individual's characteristics when looking forward to increasing the kilograms provided by the EB in squat exercises. This could be potentially useful to maximize the physical benefits derived

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from resistance exercises with variable resistance.

The squat is one of the most commonly used resistance exercises for performance and health due to its biomechanical and neuromuscular similarities to a wide range of athletic and everyday activities (Schoenfeld, 2010; Clark et al., 2012; Andersen et al., 2016; Kompf and Arandjelović, 2017). A squat program periodization is often measured or dosed by the external and internal load. Kilograms employed and the number of repetitions performed are some of the specific variables commonly used to quantify the external load, while different physiological and perceptual variables are used to quantify the internal load (Halson, 2014). For instance, the heart rate (HR), blood pressure (BP), and subjective scales of the rate of perceived exertion (RPE) are recognized as an adequate reflection of the physiological and physical performance responses, both with WP and EB (Robertson et al., 2003; Colado and Triplett, 2008; Colado et al., 2010; 2012; Halson, 2014; Maté-Muñoz et al., 2015), and are used to quantify the internal load (Halson, 2014; Iglesias-Soler et al., 2015). The most popular methods to determine training kilograms are repetitions maximum (RM) or percentage of 1RM (Reynolds et al., 2006; Bryanton et al., 2012; Aboodarda et al., 2013). Percentages of 1RM between 70 and 85% are commonly employed in resistance training programs (Kraemer et al., 2002; Schoenfeld, 2011).

The sticking region

During resistance training, when the load cannot be moved all the way upwards it is considered a failed repetition, and this often occurs in the so-called sticking region (Van den Tillaar et al., 2014; Saeterbakken et al., 2016; Andersen et al., 2016; Vigotsky et al., 2019). A sticking region has been repeatedly observed in the squat in numerous studies. Indeed, the phenomenon of the sticking region was first reported and studied in the squat (Kompf and Arandjelović, 2017). The sticking region is defined as the part of the range of motion in which a disproportionally large increase in difficulty occurs and is considered a mechanical constraint (Kompf and Arandjelović, 2016; 2017). This leads to a decrease in the upward velocity of the barbell (Van den Tillaar et al., 2014; Saeterbakken et al., 2016) and an increase in the chances of exercise form breakdown (Schoenfeld, 2010; Kompf and Arandjelović, 2016; Vigotsky et al., 2019). After this region, in the post sticking region velocity increases again due to more favorable biomechanical conditions (Van den Tillaar et al., 2014; Saeterbakken et al., 2016; Andersen et al., 2016). To locate where the sticking region finishes (sticking point) different biomechanical parameters are used such as the thigh angle relative to the ground (Kompf and Arandjelović, 2017), the knee flexion degrees (Escamilla et al., 2001), hip, knee, or even ankle joint degrees (Hales et al., 2009; Van den Tillaar et al., 2014), and so on. Focusing on the knee joint angle formed by the tibia and femur (standing position at 180º) (Figure 1), those aforementioned authors reported angles of 101.21º (Hales et al., 2009), 102º (Van den Tillaar et al., 2014) and 121º (Escamilla et al., 2001), the average being approximately 108º.

In order to overcome this biomechanical disadvantage, different techniques have been proposed such as forced repetitions, drop sets (Schoenfeld, 2011), accommodation, and use of variable resistance (EB or chains) (Kompf and Arandjelović, 2016). In particular, EB have been tested and identified as a suitable device due to providing lower loads during the more mechanical disadvantageous region of the range of motion (i.e. below the knee sticking point at lower knee angles) and greater loads with increasing knee angles (Kompf and Arandjelović, 2016; Joy et al., 2016; Andersen et al., 2016; Iversen et al., 2017). However, to the best of our knowledge, no previous research has attempted to equate the external load provided by the EB with that provided by the constant resistance in squat exercises. Bearing in mind the aforementioned strategy of incrementing the basal tension of the bands (Treiber et al., 1998; Aboodarda et al., 2013; Page et al., 2015), the question arises as to whether EB could be placed with the pertinent load immediately above the knee sticking point in a squat. This individual-based approach may create an overload in the more mechanically efficient parts of the range of motion, reducing the differences in intensity with the constant resistance and thus, maximizing the performance (Iversen et al., 2017).

Considering all the aforementioned previous research, the purpose of the present study was to analyze the physical performance (kilograms used and the number of repetitions completed), the perceived effort rate (RPE), and cardiovascular (HR and BP) responses to a squat exercise protocol on a Smith Machine when using WP or EB placed at different points of the range of motion (i.e. at standing position or immediately above the sticking point) and applying maximal and submaximal efforts. We hypothesized that depending on their application, EB will allow subjects to do a higher volume of repetitions with more kilograms in the standing position while presenting non-significant variations in the internal load.

Methods

Experimental approach to the problem

This descriptive, double-blinded study with a repeated-measures design analyzed the use of EB in six different conditions of the squat exercise on physically active healthy males. We measured the number of repetitions, and the kilograms (kg)) to quantify the external load (Halson, 2014). In addition, we analyzed RPE, systolic and diastolic blood pressure (SBP/ DBP), and HR as measurements of the internal load (Robertson et al., 2003; Colado et al., 2012; Halson, 2014; Maté-Muñoz et al., 2015; Iglesias-Soler et al., 2015; Iversen et al., 2017).

The six squat conditions were as follows: [1] 10RM (corresponding to approximately 75%1RM) with weight plates (WP) (10RMWP) loaded at standing position (i.e. body standing up straight in standard anatomical position); [2] 5RM with WP (5RMWP) loaded in the standing position, this load corresponded to approximately 85%1RM; [3] 9 submaximal repetitions with WP (9RSMWP) loaded in the standing position with the same kilograms as used for the 10RMWP condition; [4] 10 submaximal repetitions using EB (10REB) to load the bar with the same kilograms as used in the 10RMWP condition loaded in a standing position; [5] maximal number of repetitions using EB

(XRMEB) with the same kilograms as used for 10RMWP loaded in the standing position; [6] maximal number of repetitions with the same kilograms as used for 10RMWP but using EB to load the bar with the desired kilograms immediately above the estimated knee sticking point (i.e. 110º knee joint angle; fully extended knees at 180º) (Escamilla et al., 2001; Hales et al., 2009; Van den Tillaar et al., 2014; Kompf and Arandjelović, 2017) (XRMEBSP). The term weight plates (WP) was chosen over free weights due to the fixed nature of the Smith machine.

Participants

All measurements were carried out at the Optometric Clinic "Fundació Lluís Alcanyís" at the University of Valencia (Spain). We conducted the study in conformity with the Code of Ethics of the World Medical Association (Declaration of Helsinki), and permission was provided by the University of Valencia's Ethics Committee on Human Research (H1499867368458). All participants voluntarily agreed to participate and were free to withdraw from the study at any time. Each participant was informed of the benefits, and risks of injury derived from the investigation before signing an institutionally approved informed consent form.

A sample size of 19 participants was determined by a power analysis (G*Power 3.0; Faul et al., 2007) assuming an α of 0.05, a power level of 0.8, an effect size of f(V) = 0.87, and a non-sphericity correction of ε = 1. Prior to the study, all subjects received a full physical examination to assess their posture and squat technique and confirm their validity for the study. Inclusion criteria were: 1) younger than 40 years old, 2) experience on strength training for at least 6 months and performing at least 2 days per week of lower limb training including squats, and 3) no musculoskeletal health issues. As a result, of the 30 recruited subjects, only 20 met the criteria and voluntarily participated in this study. All subjects were physically active males (25.50 ± 5.26 years old, 95% confidence interval (CI) [23.04-27.96]; body mass index 24.09 ± 2.06 kg/m2, 95% CI [23.13-25.05]; body fat 10.16 ± 2.23 %, 95% CI [9.12-11.20]; Squat 1RM 127.10 ± 24.10 kg, 95% CI [115.82-138.38]; ratio 1RM- bodyweight (relative strength) 1.70 ± 0.36, 95% CI [1.55-1.85]). All participants were instructed to avoid alcohol consumption and strenuous exercise 24h before any of the sessions. They were asked to consume their typical diet, drink 1L of water, sleep for at least 8h, and not consume stimulants, supplements, or smoke before the trial. Also, water intake was controlled throughout the entire trial, allowing subjects to drink at libitum to maintain proper hydration and performance (Kenefick, 2018).

Procedures

The exercise protocol consisted of three sessions: two for familiarization and assessment, and one for the experimental trial. All data were collected in a thermoneutral environment (~ 22ºC and ~ 60% humidity), and at the same time of day to avoid diurnal variations on subjects' performance (Sundstrup et al., 2012). All measurements were taken by the same researchers and were always conducted in the same laboratory. The physiological measurements were carried out in an adjacent space separated from the Smith machine by a partition screen to blind the researcher. As for the subjects, they were instructed to not look at the Smith machine before performing each condition. Participants rested in the aforementioned separated space while listening to music with headphones to avoid getting audible information about the next condition. Constant feedback was given, and two trained spotters were standing on both sides of the bar to ensure proper execution and to encourage maximum effort.

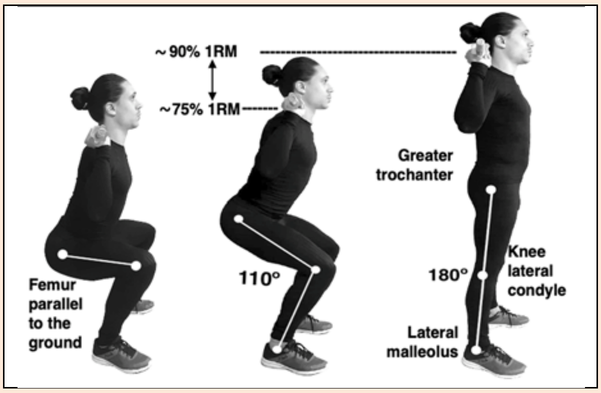

Figure 1. Relevant points of the squat performance in Condition 6. Lowest position (left), the position immediately above the estimated sticking point (middle) and standing position (right) are pictured. Anatomical points used to measure the knee angle are identified. Significant differences ($p < 0.001$; ES (d) = 1.15) on the relative load (percentages of one repetition maximum (1RM)) when adding the load immediately above the sticking point with elastic bands (Condition 6) are shown. Both 1RM percentages are rounded values, with ~75%1RM being 95.95 ± 17.88 kg [87.58-104.32], and ~90%1RM being 119.65 ± 22.86 kg [108.95-130.35].

In the first session, the participants signed the consent form, filled in the demographic questionnaire and the guarantee of data confidentiality, and underwent a physical examination. Height (m), weight (kg), and body fat percentage were obtained with a height rod and a bioelectrical impedance scale Body Composition Analyzer BF-350 (Tanita, Arlington Heights, IL). Body mass index (BMI) was calculated as weight/(height)2. Thereafter and before the warm-up, measurements of the pertinent knee angle were taken (Figure 1) and a mark was made on the Smith machine to identify the height of the bar when the subject was at this point of the range of motion. At this point, participants were instructed on how to perform the squats at the correct pace and how to use the OMNI-RES scales of perceived exertion with WP (Robertson et al., 2003) and EB (Colado et al., 2012). For further details on how to apply the RPE scales previous studies can be consulted (Maté-Muñoz et al., 2015; Naclerio and Larumbe-Zabala, 2017). The standardized warm-up included joint mobility, bodyweight exercises, jogging, and dynamic stretching. After the warm-up and before the RM testing, participants performed three sets of squats at the Smith machine: first, twenty repetitions without additional weight, and then two more sets of 15 and 12 submaximal repetitions; loads for the last two sets were selected according to participant's perceived 20RM and 15RM. Finally, maximum loads were assessed through a fatigue test with submaximal loads as previously reported in the literature (Reynolds et al., 2006). Subjects performed between 8 and 12 maximum repetitions. If a participant performed a number of repetitions that fell outside of the aforementioned range, another set with altered load was performed allowing at least a five-minutes rest; more time was permitted depending on the perception of the subjects (Laurent et al., 2011). Data were registered and used to obtain the load for 1RM using O'Connor or Brzycki formulas (Reynolds et al., 2006). Percentages were calculated for 75%1RM and 85%1RM.

A second session was used to ensure the validity of the maximum loads, the knee angle measurements, and the 75 and 85%1RM obtained during the first session, while participants gained further experience in using RPE scales. Subjects performed maximal and submaximal sets in random (https://www.random.org/lists/) order with different loads using EB and WP. If the subject was able to perform more than 10 repetitions with WP at 75%1RM or more than 5 repetitions at 85%1RM, weights were adjusted to mark the requirements.

The third session was targeted to evaluate all dependent variables. Firstly, participants underwent a physical examination to determine resting values for each physiological variable. After the warm-up, each of the six conditions was performed at random (https://www.random.org/lists/) and balanced order. For Condition 6, the bar was placed at the pertinent height and as many bands as needed to achieve the 10RM load were added. Thereafter, the bar was placed at the subject's standing position by a researcher, and afterward, the subject performed the set. All dependent variables were measured immediately after performing each condition in the following order: RPE, HR, and BP (SBP and DBP); the number of repetitions performed, and the kilograms were also recorded at that time if the condition required it. At least a five-minute rest was given between sets, more time was permitted depending on the perception of the subjects (Laurent et al., 2011).

Squat exercise

A high-bar back squat (bar placed across the shoulder on the trapezius, slightly above the posterior aspect of the deltoids) (Schoenfeld, 2010; Vigotsky et al., 2019) to a parallel depth (Clark et al., 2012; Bryanton et al., 2012; Saeterbakken et al., 2016) was performed. The stance width was established for each subject between the hips and shoulder (Schoenfeld, 2010). Shoes were used but no weightlifting belts or knee wraps were permitted (Clark et al., 2012; Vigotsky et al., 2019).

To standardize the range of motion, the sticking point, and pace of movement, a goniometer, tactile markers, and a metronome were used. The depth was adjusted with a horizontal elastic band when the femur (marked by the line from the great trochanter to the knee lateral condyle) of each subject was parallel to the ground. The participants had to touch the band (midthigh) in every repetition before starting the concentric phase. Moreover, a crossline auto-laser level was fixated with a tripod (Black and Decker LZR6TP, New Britain, CT) and was used as visual feedback for researchers in connection with the requested joint positioning during exercise. The tempo consisted in an inhalation-coordinated eccentric phase lasting two seconds (Schoenfeld, 2010) with a pause of one second at the lowest point (femur parallel to the ground), and an exhalation-coordinated maximum speed concentric phase (4 seconds for a complete squat). The pause at the transition from the eccentric to the concentric phase was designed to dissipate stored elastic energy within the muscles (Aboodarda et al., 2013).

Blood pressure and heart rate

Cardiac measurements were performed immediately after finishing each condition using a digital automatic blood pressure monitor (M6W HEM-7213-E (V), Omron, Japan). The intraclass reliability (α) of the instrument was excellent (Fleiss, 1986), being 0.90 for the SBP, 0.86 for the DBP, and 0.91 for the HR.

Rating of Perceived Exertion (RPE)

RPE for the overall body was measured immediately after finishing each of the six conditions with the OMNI-RES for weight training (Robertson et al., 2003) and the OMNI-Resistance Exercise Scale of Perceived Exertion for EB (Colado et al., 2012). These scales measure the perceived effort of the overall body (not the active muscles) in a 0-10 scale, being 0 "no effort" and 10 "maximum effort". The intraclass correlation coefficient of the RPE values given by the subjects when performing at 75 and 85%1RM in the familiarization and experimental sessions was 0.83, which is considered an excellent value (Fleiss, 1986).

Strength training equipment

A Multipower Smith Machine Powerline PSM144X (Body-Solid, USA) was loaded with 28mm cast iron plates (Domyos, France) ranging from 0.50 to 20 kg or with looped CLX elastic bands (TheraBand®, Akron, OH, USA). The barbell weighed 20 kg. To measure the load for each condition, a 100 g precision scale model 9179 SV3R (Salter, United Kingdom) was used.

Statistical analyses

Statistical analyses were performed using commercial Software IBM SPSS Statistics for Macintosh (Version 26.0; IBM Corp., Armonk, NY). A repeated-measures design was used to determine systemic variables fluctuations according to perceptual and physical performance variables after the squat exercise protocol. Normality of data distribution was evaluated using the Shapiro-Wilk test, showing a normal Gaussian distribution ($p > 0.05$) except for the RPE ($p < 0.05$). To assess differences between conditions in normally distributed variables, a one-way ANOVA for repeated measurements was used. Where Mauchly's sphericity assumptions were violated, Greenhouse-Geisser adjustment of the p-values was reported. Effect size (ES) was evaluated with eta partial squared (ηp^2), where $0.01 < \eta p^2 < 0.06$ constitutes a small effect, $0.06 \leq \eta p^2 \leq 0.14$ constitutes a medium effect, and $\eta p^2 > 0.14$ constitutes a large effect. When differences were detected, post-hoc tests with Bonferroni corrections examined where differences occurred. The magnitude of the paired differences was assessed through Cohen's effect size (ES). The results (Cohen's d coefficient) were interpreted following the specific scale to training research with negligible

(<0.2), small (0.2–0.5), moderate (0.5–0.8), and large (≥0.8) (Cohen, 1988). Non-parametric Friedman tests identified differences in RPE between conditions, and when differences were found, paired Wilcoxon signed ranks test showed where differences happened. Test-retest reliability of the instruments (blood pressure monitor and RPE scales) was assessed in a subsample of 10 subjects calculating the intraclass correlation coefficient (ICC). ICC was interpreted as poor (ICC < 0.40), moderate (0.40 ≤ ICC < 0.60), good (0.60 ≤ ICC < 0.80) or excellent (ICC ≥ 0.80) (Fleiss, 1986). An α of 0.05 was used to determine significance in all cases. All results are reported as mean and standard deviation (SD) with confidence intervals at 95%.

Results

External load

Repeated measurements testing revealed significant differences in the KG used, number of repetitions performed and reported RPE between the six conditions (KG: $F(5, 95) = 128.82$, $p < 0.001$, $\eta p^2 = 0.87$; number of repetitions: $F(5, 95) = 72.40$, $p < 0.001$, $\eta p^2 = 0.79$; RPE: $X2(5) = 64.17$, $p < 0.001$). Table 1 shows the performance variables and RPE outcomes for each of the six squatting conditions.

Adding the load for 10RM with EB immediately above the sticking point (Condition 6) resulted in a statistically significant increase of 24.7% ($p < 0.001$; ES (d) = 1.15) in the kilograms at standing position (+23.70 ± 9.45kg, 95% CI [19.27-28.12]) surpassing the theoretical 90%1RM of the participants (Figure 1). This load was also significantly higher than the 5RM load (+11.05 ± 9.02kg, 95% CI [6.83-15.27]; $p < 0.001$; ES (d) = 0.51).

While participants used significantly more kilograms, they were able to perform on average 3.45 ± 3.84 more repetitions (95% CI [1.65-5.25]) in the aforementioned Condition 6 than in Condition 1 (10RM with WP) ($p = 0.001$; ES (d) = 1.27), and 8.45 ± 3.85 more repetitions (95% CI [6.65-10.24]) than in Condition 2 (5RM with WP) ($p < 0.001$; ES (d) = 3.10). Concerning the comparison between the maximal effort at a 10RM load in the standing position with EB (Condition 5) and the 10RM with WP (Condition 1), participants performed on average 8.40 ± 4.86 more repetitions in the condition with EB (95% CI [6.13-10.67]) ($p < 0.001$; ES (d) = 2.44).

Internal load

Concerning the RPE, non-significant differences on RPE were observed between performing 10RM with WP (Condition 1) and performing about 18RM with EB (Condition 5) ($p > 0.05$). The lowest values were found in the condition comprising a submaximal effort of 10 repetitions at 10RM load with EB (Condition 4), with significant differences to the rest of the conditions (Condition 1: $p < 0.001$; ES (d) = 1.91; Condition 2: $p = 0.001$; ES (d) = 1.23; Condition 3: $p < 0.05$; ES (d) = 0.94; Condition 5: $p < 0.001$; ES (d) = 1.96; Condition 6: $p < 0.001$; ES (d) = 2.71). The condition consisting of a maximal effort with EB with 10RM load added immediately above the sticking point (Condition 6) resulted on the highest RPE, also with significant differences to the rest of the conditions (Condition 1: $p < 0.05$; ES (d) = 0.75; Condition 2: $p < 0.001$; ES (d) = 2.11; Condition 3: $p < 0.001$; ES (d) = 1.93; Condition 5: $p < 0.05$; ES (d) = 0.59).

Repeated measures testing indicated a significant BP and HR increase after each condition compared with baseline values; except for the DBP after the Condition 4 ($p = 0.075$) and 5 ($p = 0.085$). However, post-hoc analyses showed no significant differences between the six conditions on SBP or DBP. Regarding the HR, Condition 6 did not show significant differences with almost the rest of the conditions. The smallest increases were observed after a maximal effort of 5RM with WP (Condition 2: +28.00 bpm, 95%CI [18.04-37.95]), showing significant differences with the rest of the conditions. On the other hand, a maximal effort of about 18 repetitions using EB at 10RM load added at standing position (Condition 5) resulted in the highest HR, showing significant differences with all WP conditions and only a trend when compared with Condition 1 (Condition 1: $p = 0.05$; ES (d) = 0.29 ; Condition 2: $p < 0.001$; ES (d) = 0.92; Condition 3: $p < 0.05$; ES (d) = 0.35), and with the submaximal 10R with EB (Condition 4: $p < 0.01$; ES (d) = 0.53). Table 2 shows the cardiovascular variables outcomes after each condition and repeated measures testing concerning resting values; differences between conditions are also identified.

Table 1. External load variables outcomes and rate of perceived exertion of the different squatting conditions.

Condition	Kg at standing position	Number of Repetitions	RPE
1 (10RMWP)	95.95 ± 17.88 [87.58-104.32]	10.00	8.55 ± 0.88 ^{2,3,4,6} [8.14-8.96]
2 (5RMWP)	108.60 ± 20.24* [99.13-118.07]	5.00*	7.75 ± 0.72 ^{1,4,5,6} [7.41-8.09]
3 (9RSMWP)	95.95 ± 17.88 [87.58-104.32]	9.00	7.55 ± 0.99 ^{1,4,5,6} [7.09-8.01]
4 (10REB)	95.95 ± 17.88 [87.58-104.32]	10.00	6.50 ± 1.24 * [5.92-7.08]
5 (XRMEB)	95.95 ± 17.88 [87.58-104.32]	18.40 ± 4.86* [16.13-20.67]	8.65 ± 0.93 ^{2,3,4,6} [8.21-9.09]
6 (XRMEBSP)	119.65 ± 22.86* [108.95-130.35]	13.45 ± 3.84 * [11.65-15.5]	9.10 ± 0.55 * [8.84-9.36]

Note: 95.95 kg, 108.60 kg, and 119.65 kg corresponded to approximately 75%, 85% and 94% of participants' 1RM, respectively. A 20 kg barbell was used in all the conditions. *: Statistically significant difference compared to the rest of the conditions. $^{1, 2, 3, 4, 5, 6}$: Significant difference with the condition 1, 2, 3, 4, 5, or 6. Values are expressed as mean ± standard deviation (SD) [95% Confidence Interval]. RPE: rate of perceived exertion; RMWP: repetition maximum with weight plates; RSMWP: submaximal repetitions with weight plates and with the same weight used for the 10RMWP condition; EB: elastic bands; REB: submaximal repetitions with EB with the same weight used for the 10RMWP condition; XRMEB: Repetitions to failure with elastic bands with the same weight used for the 10RMWP condition; XRMEBSP: repetitions to failure with EB and loaded with the same weight used for the 10RMWP condition and placed immediately above the knee sticking point.

Table 2. Internal load outcomes of the different squatting conditions.

Condition	SBP (mmHg)	DBP (mmHg)	HR (bpm)
Resting	126.65 ± 10.65* [122.30-131.05]	68.30 ± 6.08 [1,2,3,6] [65.65-70.90]	64.05 ± 10.98* [58.91-69.19]
1 (10RMWP)	148.05 ± 20.39 [139.45-157.85]	74.25 ± 8.72 [70.35-78.10]	105.45 ± 16.35 [2,4] [97.80-113.10]
Δ%	+16.90	+8.71	+64.64
Cohen's d	1.32	0.79	2.97
2 (5RMWP)	144.00 ± 16.089 [136.95-151.35]	73.55 ± 8.79 [69.85-77.45]	92.05 ± 18.48 * [83.40-100.70]
Δ%	+13.70	+7.69	+43.72
Cohen's d	1.27	0.69	1.84
3 (9RSMWP)	146.25 ± 23.33 [137.00-156.25]	74.00 ± 7.89 [70.60-77.30]	104.20 ± 17.40 [2,5] [96.06-112.34]
Δ%	+15.48	+8.35	+62.69
Cohen's d	1.08	0.81	2.76
4 (10REB)	146.40 ± 13.39 [140.45-152.05]	72.70 ± 9.17 [68.85-76.80]	100.60 ± 16.44 [1,2,5] [92.91-108.29]
Δ%	+15.59	+6.44	+57.06
Cohen's d	1.63	0.57	2.61
5 (XRMEB)	144.55 ± 18.40 [136.95-152.75]	72.35 ± 10.06 [68.10-76.90]	111.35 ± 23.25 [1,2,3,4] [100.47-122.23]
Δ%	+14.13	+5.93	+73.85
Cohen's d	1.19	0.49	2.60
6 (XRMEBSP)	146.45 ± 19.60 [137.90-154.50]	75.35 ± 10.63 [70.60-80.05]	107.85 ± 14.63 [2] [101.00-114.70]
Δ%	+15.63	+10.32	+68.38
Cohen's d	1.26	0.81	3.39

Note: Repeated measures testing in respect to resting values are displayed. *: Statistically significant difference compared to all other conditions. [1, 2, 3, 4, 5, 6]: Significant difference compared to conditions 1, 2, 3, 4, 5, or 6. Values are expressed as mean ± standard deviation (SD) [95% Confidence Interval]. Being SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; RMWP: repetition maximum with weight plates; RSMWP: submaximal repetitions with weight plates and with the same load used for the 10RMWP condition; EB: elastic bands; REB: submaximal repetitions with EB and the same kilograms used for the 10RMWP condition; XRMEB: Repetitions to failure with elastic bands with the same kilograms used for the 10RMWP condition; XRMEBSP: repetitions to failure with EB and the same kilograms used for 10RMWP condition and placed immediately above the knee sticking point; Δ%: percentage of variation.

Discussion

This study compared the physical performance, the perceived effort rate, and cardiovascular responses to a squat protocol using different training devices (EB or WP), and with different reference points to charge the total load when EB were used (i.e. initial position of the movement versus immediately above the sticking point). To the best of our knowledge, this is the first study that analyzes the performance in a squat movement with the load added immediately above the sticking point with elastic bands and thus may have important implications for exercise prescription.

Consistent with the hypothesis, the main finding was that compared with the 10RM with WP (Condition 1), adding the load for 10RM with EB immediately above the sticking point (Condition 6) permitted participants performing about 3 more repetitions with more kilograms (25% more kilograms at standing position; see Table 1) during at least 70 degrees of knee movement (from 110º to 180º at fully extended knees; see Figure 1). This condition also permitted participants to perform about 8 more repetitions with 10% more kilograms at the standing position than in 5RM with WP (Condition 2; see Table 1). Furthermore, physiological measurements of the internal load (BP and HR) were not significantly higher than almost the rest of the conditions (see Table 2) even though participants perceived Condition 6 as the hardest. These findings highlight the usefulness of this new method of applying the elastic resistance in squats for achieving more repetitions while using more kilograms and provoking similar physiological responses. Loading the elastic resistance immediately above the squat sticking point compared to adding the load in the standing position could induce higher muscle fiber recruitment due to using more kilograms over more repetitions, which may lead to better chronic adaptations (Soria-Gila et al., 2015). Supporting this fact, increments in load for the same squat variation have been shown to produce a positive impact on muscle activation (Clark et al., 2012), and developing muscle strength has been closely related to greater force application, longer duration of muscle tension and a greater total amount of work (Schoenfeld, 2011; Bryanton et al., 2012; Aboodarda et al., 2013).

Concerning the maximal effort with EB adding the load for 10RM at standing position (Condition 5), participants performed about 8 more repetitions until exhaustion than in 10RM with WP (Condition 1). This Condition 5 was not perceived as more exhausting and did not show BP differences with the aforementioned 10RM with WP. However, Condition 5 provoked a slightly higher HR compared with Condition 1 with a small effect size (Cohen's d) of 0.29. This fact confirms that in comparison with WP, adding the same load at the standing position with EB allows for a larger time under tension while maintaining similar internal load values. A larger time under tension has been shown to increase glycolysis metabolism and may promote greater muscle adaptations by stimulating delayed muscle protein synthesis at 24-30h of recovery (Burd et al., 2012).

In reference to the submaximal conditions, EB provoked comparable internal load outcomes when kilograms at standing position and volume of repetitions are similar to the condition with WP (Conditions 3 and 4 respectively;

see Table 2). Conversely, 10 repetitions with the load for 10RM added at the standing position with EB (Condition 4) was perceived as the least demanding condition (see Table 1). This fact is probably due to having the minimum total amount of work. The similarities in the cardiovascular outcomes may be associated with the comparable number of repetitions as explained further below (see "internal load" section).

A general approach to the use of EB in squats

Bearing in mind the central target of this research, it is worth discussing the potential use of EB as a device to load the bar in squats. Within a parallel squat, muscle activation is greatest in the last phase of the descent and the first phase of the ascent (Clark et al., 2012). Knee extensors' effort increases with an increment on the squat depth, and a higher activity on hip extensors and ankle plantar flexors occurs when the barbell load increases (Bryanton et al., 2012). Since EB provide fewer kilograms in the lower part of the range of movement, and more in the upper part (Andersen et al., 2016), EB could optimally activate the neuromuscular system through the entire range of motion (Saeterbakken et al., 2014), moreover adding the load immediately above the sticking point. From a practical perspective, squatting with EB could allow the athlete to go down to the deepest point of the range of motion with less mechanical stress acting against the knees on the sticking region (Schoenfeld, 2010; Kompf and Arandjelović, 2016; Vigotsky et al., 2019). And then, immediately after this mechanical disadvantageous range of motion muscles of the hip and ankles would be enhanced with the increment in the load due to the elongation coefficient of the EB (Bryanton et al., 2012; Saeterbakken et al., 2016; Kompf and Arandjelović, 2017). Combining all these facts from a biomechanical point of view suggests that in similar conditions of load EB are an appropriate device to load the bar in squats with no need to use WP.

Nevertheless, most of the previous research has used EB with a lower tensile force or in combination with higher loads of constant resistance devices (Saeterbakken et al., 2014, 2016; Andersen et al., 2015; Iversen et al., 2017). Only some studies are in line with our procedures and have used EB to achieve similar or even higher external resistance than the one used with constant resistance devices (Colado and Triplett, 2008; Colado et al., 2010; Andersen et al., 2016; Aboodarda et al., 2013). It is important to note that in our study the weight of the barbell could be considered as constant resistance. It represented about 20% of the total load in Conditions 4 and 5, and less than 17% in Condition 6 (Table 1). Our findings support the use of EB to achieve similar or even higher loads than constant resistance devices, moreover with the new strategy of adding the load above the sticking point. However, our results should be interpreted cautiously and be compared with the existing literature.

Applying the pertinent load after the mechanical disadvantage

As far as we are aware, this is the first study that describes the acute effects of applying the load with EB in two different points of the range of motion in a squat (i.e. on the initial position of the exercise versus immediately above the sticking point). Therefore, our findings in respect of the increments in the external load when adding the elastic resistance immediately above the sticking point are difficult to compare with the existing literature. Only a few authors have similarly used EB (Treiber et al., 1998; Aboodarda et al., 2013; Page et al., 2015). For instance, Page et al. (2015) used EB initially elongated 15cm beyond their original length to perform different upper body and trunk exercises. It resulted in greater improvements in the serve of racquetball players than their usual training program. Similarly, Aboodarda et al. (2013) shortened the EB by 30% of its resting length to perform 8RM of a biceps curl on anatomical position and identified higher muscle activation levels than non-shortened EB or dumbbells at the end of the concentric phase and beginning of the eccentric phase. Results of Aboodarda et al. (2013) showed how the reduction of the basal length of the EB at the beginning of the movement is another way to increase the load above the sticking point. As happened in our study, this specific strategy allows for an increase in the kilograms moved among the less mechanically effective region of the movement, and thus an increase in muscle activation in comparison to the habitual use of the EB (Behm and Colado, 2012; 2013; Clark et al., 2012; Aboodarda et al., 2013). It also reduces differences in muscle activation compared to constant resistance in this region of the range of motion (Aboodarda et al., 2013). This strategy leads to an increase in muscle activation levels due to the possibility of using more kilograms throughout the more mechanically effective region of the movement, both in the concentric and eccentric phases (Kompf and Arandjelović, 2016, 2017; Saeterbakken et al., 2016) as has been shown in our study. It is also important to note that while we found that five less repetitions were performed between adding the load immediately above the sticking point or at standing position (Conditions 6 and 5 respectively; see Table 1), Aboodarda et al. (2013) found no difference on the number of repetitions between performing with shortened or non-shortened EB. This fact may be due to the difference in loads between both methods. They only encountered significant differences in the load at the first degrees of the concentric phase and the final segments of the eccentric phase of the biceps curl (i.e. first degrees of elbow flexion in anatomical position). In contrast, we found significantly higher loads in the last phase of the concentric and at the start of the eccentric phase of the squat exercise. These differences could be explained through the approach to the use of the EB. Our procedures are not based on elongating or shortening the EB depending on its basal length but adding the elastic resistance at different heights to overcome the sticking region depending on the athlete's biomechanics. In this regard, 110º of knee joint angle (i.e. 70º of knee flexion or a tight angle relative to the ground of 20º) seems to be a good point to add the load with the elastic bands.

From an applied point of view, our study is in agreement with other previous research regarding the possibility of lifting more kilograms when EB are added to the traditional training with WP. Joy et al. (2016) obtained positive increases in force production when implementing EB in combination with traditional constant resistance during exercises performed with concentric movements as fast as possible. These chronic positive neuromuscular adaptations were probably instigated by performing with more kilograms with the EB, overcoming the sticking point in each set of the resistance training program (Soria-Gila et al., 2015; Kompf and Arandjelović, 2016, 2017). According to our results in terms of squatting exclusively using EB, we can state that participants can load 25% more kilograms at standing position (Condition 6) than the kilograms used for a 10RM set with traditional weight plates performed at a controlled pace of movement (Condition 1; see Table 1). This could mean that it is possible to directly and easily add 25% more kilograms at the standing position with no need to measure the sticking point before beginning the exercise to add the pertinent weight. It can also be pointed out that it may be possible to add the extra kilograms with EB to the traditional WP load to obtain these benefits during a 10RM set performed with a controlled pace of movement as previously suggested in the literature (Joy et al., 2016). However, this condition has not been analyzed by us, and the final number of repetitions performed may vary.

Internal load outcomes

Our results in cardiovascular terms are in accordance with those published on HR and BP increments after high-intensity squat exercise, with greater increases after the sets with a higher number of repetitions (Iglesias-Soler et al., 2015). Cardiovascular responses seemed to be influenced by the volume rather than by the kilograms or material used.

Regarding the RPE (see Table 1), EB conditions were perceived as less demanding than WP conditions when performing at similar loads (Conditions 3 and 4). Furthermore, performing about 18RM with EB was not perceived as more demanding than performing 10RM with WP (Conditions 1 and 5 respectively). One possible explanation for the Condition 6 (load added immediately above the sticking point) being perceived by the participants as the most demanding condition could be the higher amount of total work (higher volume of repetitions performed with more kilograms). In accordance with our results (see Table 1), Sundstrup et al. (2012) reported a lower RPE after 3RM of lateral raises with EB (4.54 ± 2.09) than after repetitions to failure at approximately 15RM load also with EB (7.58 ± 2.02). Our findings are in contrast with some studies which did not find significant differences between performing at similar effort levels with elastic or constant resistance (Iversen et al., 2017). These differences may be due to using the RPE scales for the active muscles or, in contrast, for the overall body (Colado et al., 2012).

Limitations and future directions

Even though all the procedures were carefully supervised, and all statistical parameters were accurately and positively tested during the collection of data, some specific issues should be listed as potential sources of bias.

First of all, the variability between exercise protocols makes it difficult to compare results with the available literature, which limits the generalization of our findings. Regarding the load, obtained 5RM and 10RM (Table 1) are consistent with the percentages (Reynolds et al., 2006; Andersen et al., 2015) and kilograms (Joy et al., 2016) used by some studies with a varied subject population. On the other hand, some researches assessing free barbell squat reported lower average loads (Bryanton et al., 2012; Saeterbakken et al., 2016; Andersen et al., 2016; Iversen et al., 2017), and one study showed greater loads (Vigotsky et al., 2019). These differences could be explained through the variability in the sample characteristics, and the disparities of performing the squat in a Smith Machine or with a free barbell. In this respect, an increment of 14 to 23 kg has been reported when using Smith Machine due to the more stable conditions (Behm and Colado, 2012, 2013; Clark et al., 2012). Although we used a Smith Machine looking forward to ensuring equal conditions amongst all of the subjects, the study should be replicated using a free barbell. Also, this new procedure of using the sticking point to add the pertinent load could be used in different resistance exercises which have a measured sticking point such as the deadlift and the bench press. Besides, it is worth mentioning that our sample consisted only of males.

Secondly, it could be interesting to evaluate the kilograms used throughout all of the range of motion looking forward to comparing the mean external resistance between the elastic bands and the weight plates. In this regard, in different pilot studies we performed, we found a descent in the load of about 15% from the sticking point to the lowest point of the execution (in our pilot studies located at 81.12 ± 3.74 knee joint angle degrees).

Finally, as it was stated before, in the absence of more specific scientific evidence obtained with medium and long-term intervention studies, our comments are momentarily basic suggestions as to whether adaptation to applying the total weight with EB immediately above the sticking point conditions could chronically result in even higher levels of central neural activation, muscle hypertrophy, and increased strength development. All the procedures in this study were focused on identifying acute variations in the training load, and thus it would be interesting to introduce the use of the loading immediately above the sticking point with EB in a short or long-term strength periodization program to check for chronic adaptations. Also, and even though we did not analyze this condition, our results suggest that 25% more of the pertinent load could be directly added with elastic bands at the standing position with no need to measure the sticking point. While caution must be applied until more scientific evidence arrives, the strategies presented may allow the trainer or the athlete to select, according to their necessities, the optimal point of loading the resistance to maximize their physical performance and/or cardiovascular and perceptual responses.

Conclusion

The combination of findings presented provides a new approach to the use of elastic bands for strength training exercises. In summary, our findings showed that depending on how the bands are applied (i.e. immediately above the sticking point or at the standing position), squatting with

EB: 1) allows the participants to move more kilograms after the sticking region than squatting only with WP, 2) facilitates a higher number of repetitions, which could permit a greater time of muscle activity or time under tension (i.e. how long a muscle is under strain during a set), and 3) optimizes cardiovascular responses and perceived effort rating.

Bearing in mind these abovementioned facts, the evidence presented in this study highlights the possible practical applications of EB for subjects who need to exercise with high loads. Additionally, those subjects who want to avoid high cardiovascular and perceptual stress during strength training, without reducing muscular demands could also safely use EB in different ways. In conclusion, elastic bands could reduce cardiovascular and perceptual stress depending on each type of application and are presented as a solid option to perform resistance training at high loads and volumes with no need to combine them with weight plates.

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Key points

- This paper presents a new strategy of applying the elastic bands for resistance exercises (i.e. immediately above the sticking point).
- Adding the load immediately above the sticking point with elastic bands allow to achieve more repetitions and use more weight than weight plates do.
- Blood pressure and heart rate responses are similar to a 10RM with weight plates or an 18.40RM with elastic bands.
- When both elastic bands and weight plates are equated in weight (at standing position), volume and level of effort (submaximal), elastic bands are perceived by the subjects as less demanding.

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