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REVIEW/META-ANALYSIS

ECCENTRIC AND CONCENTRIC JUMPING PERFORMANCE DURING AUGMENTED JUMPS WITH ELASTIC RESISTANCE: A META-ANALYSIS

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ABSTRACT

Introduction: The initial rapid eccentric contraction of a stretch-shortening cycle (SSC) activity is typically reported to accentuate the subsequent concentric jump performance. Some researchers have rationalized that adding elastic resistance (ER) to explosive type activities (e.g. countermovement jumps and drop jumps) would increase excitatory stretch reflex activity and mechanical recoil characteristics of the musculotendinous tissues. The purpose of this meta-analysis was to examine the available literature on jumping movements augmented with ER and to provide a quantitative summary on the effectiveness of this technique for enhancing acute eccentric and concentric jumping performance.

Methods: In a random-effects model, the Hedges`s g effect size (ES) was used to calculate the biased corrected standardized mean difference between the augmented and similar non-augmented jumps.

Results: The results demonstrated that augmented jumps provided a greater eccentric loading compared to free jumps (Hedges`s g ES = 0.237, $p = 0.028$). However the concentric performance was significantly impaired, particularly if the downward elastic force was used during concentric phase as well (ES= -2.440, $p < 0.001$). Interestingly, no performance decrement was observed in those studies, which released the bands at the beginning of the concentric phase (ES = 0.397, $p = 0.429$).

Discussion: The authors postulated that the excessive eccentric loading might trigger reflex inhibition, alter the muscle stiffness, increase downward hip displacement and dissipate mechanical recoil properties. These results suggest that the release of elastic force at the beginning of the concentric phase seems to be a critical point to avoid impairment of acute concentric performance in augmented jumps.

Level of Evidence: 2a

Keywords: Elastic tubing, exercise bands, surgical tubing, stretch-shortening cycle, strength, power

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Conflicts of Interest: Dr. Aboodarda and Dr. Behm have no financial or perceived conflicts of interest. Dr. Page is the Director of Clinical Education and Research for Performance Health Inc., which manufactures and distributes similar products (TheraBand).

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INTRODUCTION

Elastic resistance (ER) devices including elastic bands, rubber bands, and tubing (surgical tubing, sport cords and bungy cords) are portable, low cost, and easy maintenance training devices, which have been utilized alone or in conjunction with other training devices to provide resistance in strength and power training programs.[1-6] The ER provides both mechanical advantages and disadvantages when compared to traditional free weight and machine resistance devices.[7-12] Some investigators postulated that due to inadequate external force, ER may not elicit maximal muscle tension in the active muscles.[13] However, the proponents of ER recommended that by employing a simple adjustment in the initial length of the elastic material[14,15] and using additional units of elastic bands in parallel[3,16] an adequate increase in elastic force will be provided, which can lead the active muscles to develop tension across the entire concentric phase.[17,18]

In order to optimize the magnitude of external load provided by ER, some investigators have examined the combination of resistance generated by fixed loads (e.g. barbell) and the ER.[19,20] Using this technique has also been postulated to overcome the mechanical disadvantage of free weights exercises (i.e. decreased resistive force once inertia is overcome and momentum increases).[20-24] In a comprehensive meta-analysis, Soria-Gila and colleagues[25] have examined the research-based effect of ER plus free-weight loaded training on muscular strength gains during bench press and squat exercises and suggested that this could be an effective technique to improve maximal strength (i.e. 1 repetition maximum) both in athletes and untrained subjects.

The present meta-analysis is focused on the application of ER during explosive exercises such as countermovement jump (CMJ) and drop jump (DJ).[26-28] The augmented body mass and gravitational acceleration induced by ER during the eccentric phase of jumping movements is thought to amplify the stretch-shortening cycle (SSC) mechanism (a detailed discussion of the SSC is beyond the focus of the present paper, for more information the reader is directed to references[29,30]). Investigators have speculated that during augmented jumps, the active muscles experience a greater pre-stretch state during the eccentric phase, which can generate and store elastic energy in the contractile components of musculotendinous structures and enhance the myoelectric potentiation and the stretch reflex mechanisms.[29,31-33] The release of this stored elastic energy during the concentric phase may result in improvement of subsequent force and power generating capability during jumping, running and other SSC type activities.[28,31,34,35] Although there have been a number of studies investigating primarily the acute kinetic and kinematic variables during augmented jumps with ER,[26-28,35,36] there has not been a systematic review of the literature conducted which synthesizes previous data and provides summative information about the effectiveness of augmented jumps with ER on acute eccentric and concentric jumping performance. Therefore, the purpose of this meta-analysis was to examine the available literature on jumping movements augmented with ER and to provide a quantitative summary on the effectiveness of this technique for enhancing acute eccentric and concentric jumping performance.

METHODS

Search strategy and inclusion/exclusion criteria

This review of the literature included studies that examined the effect of using additional ER during CMJ or DJ movements on acute eccentric and concentric jumping performance. A literature search was performed by the three authors separately and independently using MEDLINE, SPORT Discus, ScienceDirect, Web of Science and Google Scholar databases. The topic was searched using a combination of keywords including: elastic tubing, elastic bands, exercise cord, Thera-Band, elastic resistance training, elastic band exercises, bungy exercise, augmented resistance training, accentuated jump, countermovement jump, drop jump, augmented elastic training, loaded resistance training, and loaded elastic exercise. All references from the selected articles were also manually crosschecked by the authors to identify relevant studies that might have been missed in the search and to eliminate duplicates.

Inclusion Criteria (study selection)

Studies examining the acute effects of jumping movements augmented with ER on concentric and eccentric jumping performance were included in the review if they fulfilled the following selection criteria: 1) the study investigated the effect of using ER during augmented CMJ or DJ on eccentric or concentric jumping performance, 2) the study quantified and compared at least one of the following measurements between an augmented jump with ER and a free (non-augmented) jump: eccentric and/or concentric peak ground reaction force (GRF), mean GRF, peak impulse, mean impulse, peak power, or mean power. Since a faster peak eccentric loading (lengthening) may amplify the SCC mechanism and enhance take off velocity and performance,[29,37,38] studies which reported peak velocity were also included to the meta-analysis, 3) the study used healthy, active human subjects, 4) the study was written in English and published between 1987 – 2015 and 5) the study was published in a peer-reviewed journal (abstracts and unpublished studies were excluded). Studies were excluded if 1) elastic resistance was a part of a mechanical training device (e.g. Vertimax) and 2) other movements except CMJ and DJ were studied.

Meta-analytic statistical comparisons were made with the Comprehensive Meta-analysis software (BioStat Inc. Englewood, New Jersey, USA). A random-effects model was used to examine the grouped data extracted from the different studies. The Hedges`s g effect size (ES) was used to calculate the biased corrected standardized mean difference between the ER augmented and similar non-augmented jumps. ES calculations were conducted to evaluate the magnitude of the difference according to the criterion of 0.80 large; 0.50 medium and 0.20 small. The Hedges`s g ES was calculated based on the mean and standard deviation of the two modes of jumps using one of the following variables: peak GRF, mean GRF, peak velocity, peak impulse, mean impulse, peak power, mean power. In order to address the influence of using ER on eccentric and concentric phases of jumping performance, separate analyses were performed the two phases. The Hedges`s g ES and 95% CIs for the outcomes of each study were illustrated in a forest plots.

The examination of inter-study heterogeneity was based on computing the weighted sum of squares [Q value] of the effect sizes included with the meta-analysis. The difference of every effect size from the mean effect size was calculated and squared. Then, the sum the weighted squares was computed. The I-squared (I^2) and the p-values ($p < 0.05$) were also considered to determine if the dispersion observed in the forest plot reflects difference in the true effect sizes or random sampling error.[39]

RESULTS

From 41 full text articles assessed for eligibility, five articles met the inclusion criteria for the meta-analysis. Four studies employed the recoil force of ER during entire eccentric phase of jumps (Figure 1).

For CMJ, the eccentric phase included from the initiation of lowering the center of mass to the lowest displacement of the hip while for DJs, the eccentric

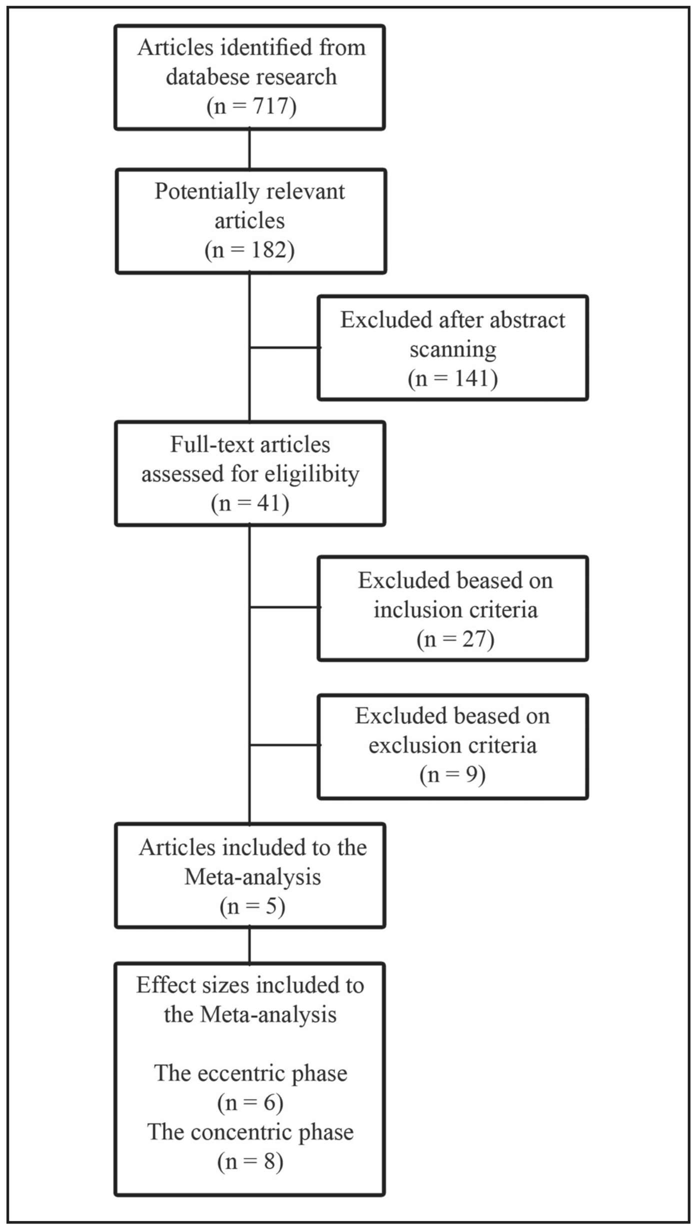

Figure 1. *Study selection/inclusion process*

phase encompassed the entire landing phase to the lowest displacement of the hip. Therefore one meta-analysis was performed to measure the effect of ER on the eccentric jumping performance. However, in two of the five included studies[28,36] that quantified concentric performance, the elastic bands were released during the concentric phase of the movement, once the subject reached full flexion of hip and knee during both types of jumps. Since it had been hypothesised that using this technique could eliminate the restriction of the ER external load and facilitate the concentric power production, separate analyses were conducted to quantify and compare the concentric performance between the studies whose methods involved release of the bands and those whose methods did not. In addition, since various resistance of ER might provide different acute effects on eccentric and concentric performance, separate data points from Aboodarda et al[28,36] (who used ER equivalent to 20% and 30% of bodyweight) and Markovic and Jaric`s[35] (who used ER equivalent to 15% and 30% of bodyweight) are presented in the analysis (Table 1).

Eccentric jumping performance

Table 2 displays data from the four studies that met the inclusion criteria for the meta-analysis. Six effect sizes (from the four studies) were included to the analysis. Eccentric peak power,[28] peak ground reaction force,[27] peak impulse[36] and peak velocity[26] were the variables which were included to show the effect of using ER on eccentric jumping performance. The overall effect obtained from 78 males, all trained with a minimum of six months of strength-training

Table 1. *Details of the studies included in the meta-analysis. Acronyms: CMJ: countermovement jump, ACMJ: augmented CMJ, FCMJ: free CMJ, DJ: drop jump, ADJ: augmented DJ, FDJ: free DJ, M: males, F: females, BW: body weight, RT: resistance trained, ER: elastic resistance, RRM: randomized repeated measure, PP: peak power, PV: peak velocity, VGRF: vertical ground reaction force, RFD: rate of force development. * indicates that in these studies the elastic bands were released at the beginning of concentric phase.*

Study Name	Study type	N (M/F)	Age (±SD) (years)	Trained level	Intervention	Measurements used in the Meta-analysis	Other Measurements of the study
Aboodarda et al[28]*	RRM	15 M	22.6 ± 5.3	Trained with RT experience > 1 year	FCMJ (control) ACMJ 20% BW ACMJ 30% BW	Eccentric PP Concentric PP	VGRF, Impulse, Jump height
Aboodarda et al[36]*	RRM	15 M	24.7 ± 5.7	Trained with RT experience > 5 years	FDJ ADJ 20%BW ADJ 30% BW	Eccentric impulse Concentric impulse	RFD Take of velocity Duration Jump height
Argus et al[27]	RRM	8 M	27.5 ± 5.5	Trained with RT experience > 6 month	FCMJ ACMJ	Eccentric GRF Concentric PP	Peak velocity Peak force
Cronin et al[26]	RRM	10 M	24.2 + 2.3	Trained with RT experience > 3 years	CMJ on isoinertial (ISO) supine squat machine CMJ on (ISO) + 20-30kg bungy ER	Eccentric PV Concentric PV	Mean velocity Time to peak Velocity EMG
Markovic & Jaric[35]	RRM	15 M	23.5 ± 3.4	Trained with RT experience > 1 year	FCMJ ACMJ 15% BW ACMJ 30% BW	Concentric PP	Concentric Mean power Momentum PV Duration

RRM= repeated measures , M= males, RT= resistance training, FCMJ= free countermovement jump, ACMJ= augmented countermovement jump, FDJ= free drop jump, ADJ= augmented drop jump, ER= elastic resistance, PP= peak power, GRF= ground reaction force, PV= peak velocity, VGRF= vertical ground reaction force, EMG= electromyography experience, demonstrated that augmented jumps provided greater eccentric loading compared to free jumps (Hedges`s g ES= 0.237, CI: 0.025 to 0.448, $p = 0.028$) (Table 2). The data presented in Figure 2 showed large CIs for each estimate, which indicate a poor precision for each study (i.e. large intra-study variance). However there was very small inter-study variation between different estimates (Q-value = *0.738*, $p = 0.981$, $I^2 < 0.001$), which suggest that there was no heterogeneity between the observed effect sizes. In other words, the true effect sizes between studies were almost identical and 98% of the inter-study variation was due to sampling error that could be attributed to variables such as smaller sample size, biased sampling, targeting an available population and other factors.

Concentric jumping performance

Table 3 presents data from the five studies met the inclusion criteria for the meta-analysis. Eight ESs (from the five studies) were included in the analysis of concentric peak power,[27,28,35] peak impulse[36] and peak velocity[26] variables. The overall effect obtained from 108 males, all trained with a minimum of six months of strength-training experience, demonstrated that augmented jumps with ER impaired concentric performance compared to free jumps (Hedges`s g ES= -0.776, CI: -1.528 to -0.023, $p = 0.043$) (Table 3). The data presented in Figure 3 exhibited a high inter-study dispersion between different estimates, which suggests that there was a very high heterogeneity between the effect sizes of the included studies (Q-value = *79.088*, $p < 0.001$, $I^2 = 91.149$).

Table 2. *Results of the four studies included in the meta-analysis measuring eccentric performance.*

Study Name	Hedges`s g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aboodarda[28], 20% BW, CMJ	0.209	0.247	0.061	-0.275	0.693	0.845	0.398
Aboodarda[28], 30%BW, CMJ	0.346	0.252	0.064	-0.148	0.840	1.372	0.170
Aboodarda[36], 20%BW, DJ	0.129	0.245	0.060	-0.352	0.609	0.525	0.599
Aboodarda[36], 30%BW, DJ	0.343	0.252	0.064	-0.151	0.837	1.362	0.173
Cronin[26], 20-30 kg, CMJ	0.120	0.290	0.084	-0.449	0.690	0.415	0.678
Argus[27], 20%BW, CMJ	0.260	0.321	0.103	-0.369	0.889	0.810	0.418
Overall	0.237	0.108	0.012	0.025	0.448	2.195	0.028

BW= body weight, CMJ= countermovement jump, DJ= drop jump

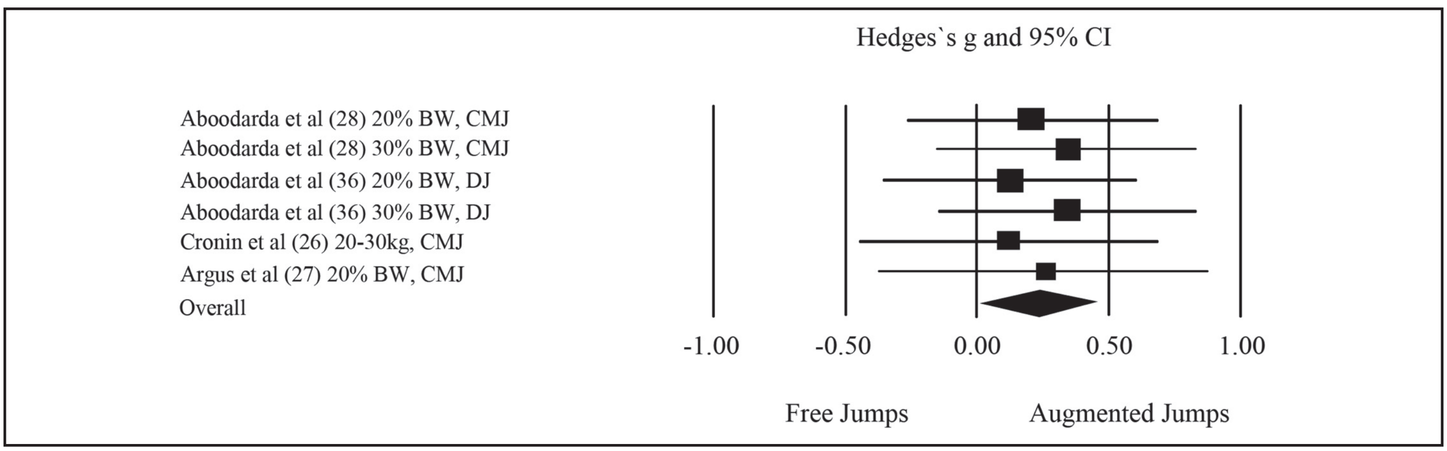

Figure 2. *Forest plot presenting the results of the Hedges`s g ES and 95% CIs for the eccentric performance. Six effect sizes were included in the analysis. Eccentric peak power,[27,28] peak impulse[36] and peak velocity[26] were the variables which included in the analysis. The augmented jumps with ER provided a greater eccentric loading compared to free jumps (Hedges`s g ES= 0.237, CI: 0.025 to 0.448,* p = 0.028*). The horizontal line demonstrates the lower and the upper limits of the effect at a 95% CI. The filled square (■) indicates the ES for each study. The filled diamond (♦) indicates the pooled effect size.*

Table 3. *Results of the four studies included in the meta-analysis measuring concentric performance.*

Study Name	Groups by	Hedges`s g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Argus[27], 20%BW, CMJ	With bands	-1.928	0.575	0.331	-3.056	-0.800	-3.351	0.001
Cronin[26], 20-30 kg, CMJ	With bands	0.035	0.289	0.084	-0.532	0.602	0.122	0.903
Markovic and Jeric [35], 15% BW, CMJ	With bands	-4.255	0.814	0.663	-5.850	-2.659	-5.225	0.000
Markovic and Jeric [35], 30% BW, CMJ	With bands	-6.556	1.222	1.492	-8.950	-4.161	-5.367	0.000
Subgroup pooled data		-2.440	0.597	0.357	-3.611	-1.270	-4.085	0.000
Aboodarda[28], 20% BW, CMJ	Without bands	0.059	0.244	0.060	-0.420	0.538	0.241	0.809
Aboodarda[28], 30%BW, CMJ	Without bands	0.493	0.260	0.068	-0.017	1.003	1.894	0.058
Aboodarda[36], 20%BW, DJ	Without bands	0.285	0.250	0.062	-0.204	0.774	1.142	0.254
Aboodarda[36], 30%BW, DJ	Without bands	0.758	0.281	0.079	0.208	1.308	2.701	0.007
Subgroup pooled data		0.397	0.501	0.251	-0.586	1.379	0.792	0.429
Overall		-0.776	0.384	0.147	-1.528	-0.023	-2.020	0.043

BW= body weight, CMJ= countermovement jump, DJ= drop jump

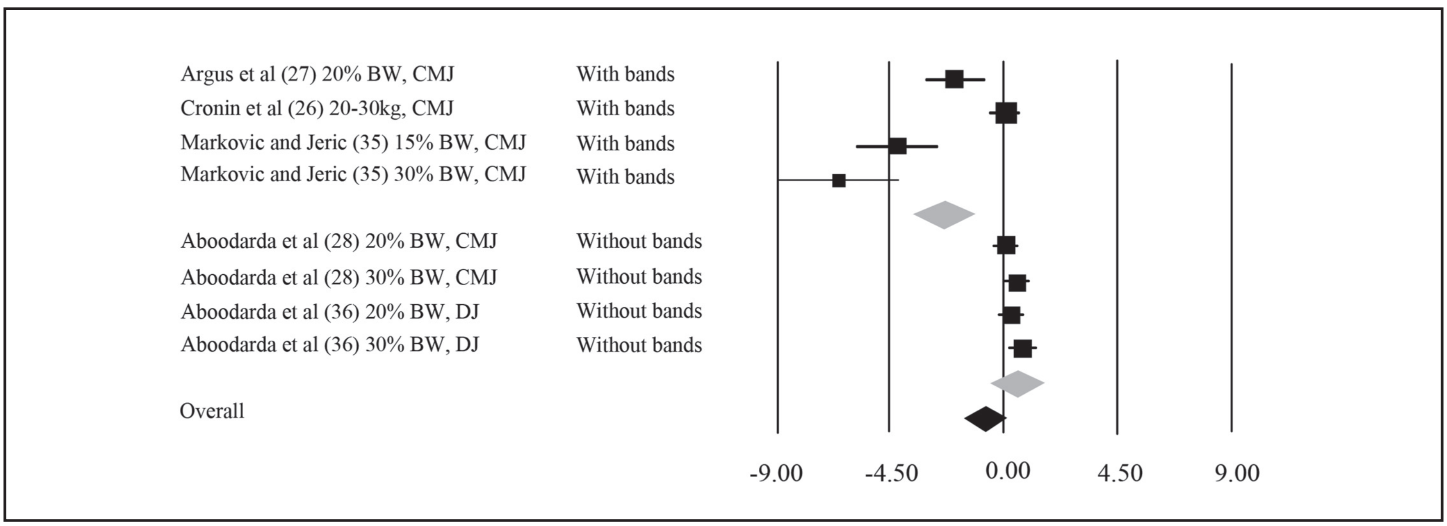

Figure 3. *Forest plot presenting the results of the Hedges`s g ES and 95% CIs for the concentric performance. Eight effect sizes were included in the analysis. Concentric peak power,[27,28,35] peak impulse[36] and peak velocity[26] were the variables which included in the analysis. The overall effect demonstrated that augmented jumps with ER impaired concentric performance compared to free jumps (Hedges`s g ES= -0.776, CI: -1.528 to -0.023, p = 0.043). There was a significant impairment for those studies which the bands were kept attached (Hedges`s g ES= -2.440, CI: -3.611 to -1.270, p < 0.001); however, no performance decrement was observed for those studies which the bands were released (Hedges`s g ES= 0.397, CI: -0.586 to 1.379, p = 0.429). The horizontal line demonstrates the lower and the upper limits of the effect at a 95% CI. The filled square (■) indicates the ES for each study. The grey diamonds (♦) indicates the pooled effect size for the two subgroup studies (with bands vs. without bands). The black diamond (♦) indicates the pooled effect size.*

Further analysis of the two subgroups of studies in which elastic bands were kept attached during concentric phase of jump and those during which the bands were released at the beginning of concentric phase produced distinctive results. Interestingly, there was a significant impairment in the concentric performance for those studies during which the bands were kept attached (Hedges`s g ES= -2.440, CI: -3.611 to -1.270, $p < 0.001$); however, no performance decrement was observed for those studies during which the bands were released (Hedges`s g ES= 0.397, CI: -0.586 to 1.379, $p = 0.429$). Furthermore, there was a large heterogeneity between the effect sizes of those studies, which did not release the bands (Q-value = *52.022*, $p < 0.001$, $I^2 = 94.233$) and moderate heterogeneity was evident between studies in which the bands were released (Q-value = *3.870*, $p = 0.276$, $I^2 = 22.479$).

DISCUSSION

The most important findings of the current meta-analysis were that the addition of ER to the CMJs and DJs could significantly increase the eccentric loading, as measured by eccentric peak power, peak impulse and peak velocity. However, this greater eccentric loading could lead to decreases in concentric performance if the bands were not released at the beginning of concentric phase. In light of this observation, releasing the force exerted by elastic resistance, at the beginning of concentric phase, seems to be critical to avoiding impairment of acute concentric performance.

The sequencing of fast eccentric (stretching) and concentric (shortening) actions has been shown to enhance jumping performance.[29,31-33] The rationale for augmenting explosive exercises such as CMJ and DJ with ER is to take advantage of the physiological components associated with the SSC mechanism in order to increase concentric power output.[28,32,34,40] In addition to the SSC reflexive component,[41,42] the visco-elastic characteristic of the musculotendinous tissues as well as the fiber cross-bridges may store elastic energy during an initial rapidly performed eccentric movement after which release of the stored energy may improve concentric performance.[29,43,44]

The six effect sizes (from the four studies) used to examine the effect of augmented jumps on eccentric responses indicated that the additional ER improved eccentric loading evident in eccentric peak power, GRF, impulse and velocity. Although this finding was in line with the authors' expectation, only a small effect size was observed for this improvement (ES= 0.237), which could be attributed to 1) the small magnitude of elastic load utilized during augmented jumps (15 to 30% bodyweight), 2) the large intra-study variance observed for the included ESs (Figure 2). Nonetheless, a small inter-study variance was observed for the overall ES (variance = 0.012), which indicates that the increased eccentric loading was a consistent phenomenon between the six included studies.

However, contrary to the hypothesis that a faster and greater eccentric loading can improve concentric jumping output, the results of this meta-analysis indicate that the concentric performance was diminished or impaired during augmented jumps compared to the control condition. More specifically, the results of this meta-analysis demonstrated a large negative effect size (ES= -2.440) for the acute concentric performance measured by concentric peak power, impulse, and velocity for those studies in which equal magnitude of ER was applied during both concentric and eccentric phases.[27,35] However, interestingly, no impairment was observed in concentric performance (ES = 0.397) when the elastic bands were released at the beginning of concentric phase.[28,36] In other words, as presented in Figure 3, the large negative ESs from the studies by Markovic and Jeric[35] and Argus et al[27] studies contributed significantly to shift the overall effect toward a negative value. The study by Cronin et al[26] seems to be an exception to this trend because although they used downward tensile load during both eccentric and concentric phases of CMJs, they did not observe any impairment in concentric peak velocity. Although the actual reason for the disparity between these findings is unclear, there are a number factors that could diminish the beneficial effects of adding elastic resistance to explosive exercises such as CMJ and DJ.

Whereas elastic resistance can increase eccentric velocity and VGRF possibly facilitating reflexive and mechanical SSC responses, the additional load during the concentric phase could hinder take-off velocities. In line with this explanation, the two studies which demonstrated the highest impairment in concentric jumping performance[27,35] reported significant decreases in peak concentric velocity when compared to no additional ER. The concept of specificity of training velocity[45,46] indicates that the training velocity should match as closely as possible to the competition or event velocity, thus, a decreased concentric velocity might adversely affect training responses. In order to address this difficulty, Aboodarda and colleagues[28] modified the augmented CMJ with ER by releasing the elastic bands immediately prior to the concentric phase. They demonstrated that this technique could enhance jump height performance and takeoff velocity as measured with a force plate and motion analysis system. However, the release of the elastic bands immediately before the concentric phase of DJs did not change the takeoff velocity and concentric impulse compared to the control condition.[36] Unfortunately, few studies have employed the release of ER method to enhance jumping performance; therefore, further research is required to investigate effectiveness of using ER during different modalities of augmented jumps.

Other potential explanations for failure in transfer of greater eccentric loading to concentric jumping performance could be: 1) the timing and magnitude of muscle preactivation before the start of the eccentric phase, 2) the prolonged length of eccentric phase and 3) the protracted amortization period between eccentric and concentric phase.[47] In order to achieve greatest possible jump height, it is important to perform the eccentric phase of jump with an adequate muscle pre-activation in order to generate an optimal level of leg stiffness.[48,49] Athletes develop an optimal strategy to pre-activate muscles for different type of activities. This anticipatory strategy has been demonstrated with DJs,[50,51] hopping,[31] jumping drills,[52] and maximum sprinting.[53] The increased eccentric loading during augmented jumps may disrupt the pre-activation strategy and provide a dampening effect on muscle stiffness. Aboodarda et al[36] showed no change or slightly shorter eccentric durations of DJs in response to the addition of elastic resistance. Subjects demonstrated earlier onset of EMG activity for all studied muscle groups during loaded DJs suggesting an increased leg stiffness response to additional eccentric loading by ER. The purpose of this anticipatory modulation of muscle activation patterns is to decelerate and eventually terminate the joint rotations and to provide adequate muscle tension for absorption of the impact force.[54,55] The increased elastic resistance load may have caused Aboodarda's subjects to focus more on impact absorption and therefore less on explosiveness during the concentric phase. More specifically, excessive eccentric loading may necessitate a greater amount of joint excursion in order to absorb the higher VGRF which can elongate the delay between the eccentric and concentric contraction phases and result in dissipation of the stored elastic in the form of heat.[56]

Excessive eccentric loading might also increase Golgi-tendon inhibitory Ib afferent responses minimizing muscle activation benefits associated with SSC mechanism.[57-59] Fetz et al[60] reported that in addition to possible Ib afferent inhibition, that the inhibition of motoneurons may also be evoked from homonymous and synergistic Ia muscle spindle afferents. Aboodarda et al[36] contradicted the hypothesis that augmented DJs would increase muscle spindle stretch reflex activity leading to increased motoneuronal output[30,58] with their report of no significant EMG differences between loaded and unloaded DJs during the concentric phase. Aboodarda's findings were in line with those reported by Bobbert et al[38] that did not exhibit higher EMG values for the knee extensors and plantar flexors despite larger knee and ankle moments in DJs with faster eccentric loading. These findings might be related to the population used in these three studies as it is possible that highly motivated and trained individuals are at or close to their maximum potential and thus there is minimal contribution from an already fully activated stretch reflex system.

The major limitation of this meta-analysis is the few comparable studies available. The low number of total subjects would also contribute to the high inter-study variability. Furthermore, instructions to participants regarding jump technique (particularly during landing phase) could have differed between studies leading to significant differences in concentric and eccentric performance. In addition, a variety of elastic materials were used in the included studies, which could have provided different resistance and loading patterns.

CONCLUSIONS

The results of this meta-analysis suggest that the addition of ER to the CMJs and DJs can significantly increase the eccentric loading; however, greater eccentric loading may not be translated to an enhanced concentric performance. In particular, the concentric responses may considerably be impaired if the elastic bands are not released at the beginning of concentric phase. The authors postulated that the excessive eccentric loading might trigger reflex inhibition (Ia and Ib afferents), alter the anticipatory EMG responses affecting muscle stiffness, increase downward displacement of the hip and dissipate mechanical recoil properties. It`s worth noting that the current results should only be interpreted in the context of the acute effects on eccentric and concentric jumping performances. Therefore, the possible potential benefits of augmented jumps with ER as an effective technique for increasing eccentric loading and the long-term effects of ER for enhancing concentric performance needs to be studied.

REFERENCES

1. Behm DG. Strength and power conditioning for racquet sports. *Natl Strength Cond Assoc J*. 1987; 9(1): 37-41.
2. Behm DG. An analysis of intermediate speed resistance exercises for velocity-specific strength gains. *J Appl Sport Sci Res.* 1991; 5:1-5.
3. Page JL, Ben A, Robert B, Robert C, Robert C. Posterior rotator cuff strengthening using Theraband® in a functional diagonal pattern in collegiate baseball pitchers. *J Athl Train.* 1993; *28*:346-354.
4. Page P, Ellenbecker T. *The Scientific and Clinical Application of Elastic Resistance.* Champaign, IL, Human Kinetics; 2003.
5. Hodges GN. *The effect of movement strategy and elastic starting strain on shoulder resultant joint moment during elastic resistance exercise.* Master of Science Thesis, School of Medical Rehabilitation, Faculty of Medicine, University of Manitoba; 2006.
6. Anderson CE, Sforzo GA, Sigg JA. The effects of combining elastic and free weight resistance on strength and power in athletes. *J Strength Cond Res.* 2008; 22:567-574.
7. Behm DG. Surgical tubing for sport and velocity specific training. *Strength Cond Assoc J*. 1988; 10(4):66-70.
8. Hintermeister RA, Bey MJ, Lange GW, Steadman JR, Illman CJ. Quantification of elastic resistance knee rehabilitation exercises. *J Orthop Sport Phys Ther.* 1998; *28*(1):40-50.
9. Hughes CJ, Hurd K, Jones A, Sprigle S. Resistance properties of Thera-Band® tubing during shoulder abduction exercise. *J Orthop Sport Phys Ther.* 1999; *29*(7):413-420.
10. Simoneau GG, Bereda SM, Sobush DC, Starsky AJ. Biomechanics of elastic tesistance in yherapeutic rxercise programs. *J Orthop Sport Phys Ther.* 2001; *31*(1):16-24.
11. Colado JC, Garcia-Masso X, Pellicer M, Alakhdar Y, Benavent J, Cabeza-Ruiz R. A comparison of elastic tubing and isotonic resistance exercises. *Int J Sports Med*. 2010; 31(11):810-7.
12. Jakobsen MD, Sundstrup E, Andersen CH, Aagaard P, Andersen LL. Muscle activity during leg strengthening exercise using free weights and elastic resistance: effects of ballistic vs controlled contractions. *Hum Mov Sci.* 2013; 32(1):65-78.
13. Matheson JW, Kernozek TW, Fater DC, and Davies GJ. Electromyographic activity and applied load during seated quadriceps exercises. *Med Sci Sports Exerc.* 2001; *33*(10):1713-1725.
14. Treiber FA, Lott J, Duncan J, Slavens G, Davis H. Effects of Theraband and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. *Am J Sports Med.* 1998; *26*(4):510-515.
15. Aboodarda SJ, Hamid MS, Che Muhamed AM, Ibrahim F and Thompson M. Resultant muscle torque and electromyographic activity during high intensity elastic resistance and free weight exercises. *Eur J Sport Sci*. 2013; 13(2): 155-163.
16. Aboodarda SJ, Ibrahim F, Hamid MS, Che Muhamed AM, Yusof A. Resultant muscle torque and EMG activity during high intensity elastic resistance and nautilus machine exercises. *J Hum Kinetics.* 2011; 30:5-13.
17. Muhitch L. *Electromyographic investigation of free weights and Thera-Band*. State University of New York College at Cortland, New York, USA (Master Thesis); 2006.
18. Andersen LL, Andersen CH, Mortensen OS, Poulsen OM, Bjørnlund, IBT, Zebis MK. Muscle activation and perceived loading during rehabilitation exercises: Comparison of dumbbells and elastic resistance. *Phys Ther*, 2010; 90:538–549.
19. Ebben WE, Jensen RL. Electromyographic and kinetic analysis of traditional, chain, and elastic band squats. *J Strength Cond Res*. 2002; 16:547-550.
20. Ghigiarelli JJ, Nagle EF, Gross FL, Robertson RJ, Irrgang JJ, Myslinski T. The effects of a 7-week heavy elastic band and weight chain program on upper-body strength and upper-body power in a sample of division 1-AA football players. *J Strength Cond Res.* 2009; 23(3):756-64.
21. McCurdy K, Langford G, Ernest J, Jenkerson D, Doscher M. Comparison of chain- and plate-loaded

bench press training on strength, joint pain, and muscle soreness in division II baseball players. *J Strength Cond Res.* 2009; 23:187-195.

22. Rhea MR, Kenn JG, Dermody BM. Alterations in speed of squat movement and the use of accommodated resistance among college athletes training for power. *J Strength Cond Res.* 2009; 23:2645-2650.
23. Bellar DM, Muller MD, Barkley JE, Kim C, Ida K, Ryan EJ, Bliss MV, and Glickman EL. The effects of combined elastic- and free-weight tension vs. free-weight tension on one-repetition maximum strength in the bench press. *J Strength Cond Res.* 2011; 25:459-463.
24. Shoepe TC, Ramirez DA, Rovetti RJ, Kohler DR, Almstedt HC. The effects of 24 weeks of resistance training with simultaneous elastic and free weight loading on muscular performance of novice lifters. *J Hum Kinet.* 2011; 29:93-106.
25. Soria-Gila MA, Chirosa I, Bautista I, Baena S, Chirosa LJ. Effects of variable resistance training on maximal strength: A meta-analysis. *J Strength Cond Res.* Publish Ahead of Print. 2015; DOI: 10.1519/JSC.0000000000000971
26. Cronin J, McNair P, Marshall R. The effects of bungy weight training on muscle function and functional performance. *J Sports Sci.* 2003; 21:59–71.
27. Argus CK, Gill ND, Keogh JW, Blazevich AJ, Hopkins WG. Kinetic and training comparisons between assisted, resisted, and free countermovement jumps. *J Strength Cond Res.* 2011; 25:2219-2227.
28. Aboodarda SJ, Yusof A, Abu Osman NA, Thompson MW, Mokhtar AH. Enhanced performance with elastic resistance during the eccentric phase of a countermovement jump. *Int J Sports Physiol Perform*. 2013; 8:181–187.
29. Komi PV, Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. *Med Sci Sports.* 1978; 10:261-265.
30. Komi PV. Stretch-shortening cycle. In: Komi PV, ed. *Strength and Power in Sport.* Oxford, UK: Blackwell Science; 1992:169-179.
31. Hobara H, Kanosue K, Suzuki S. Changes in muscle activity with increase in leg stiffness during hopping, *Neuroscience Letters.* 2007; 418: 55–59.
32. Sheppard J, Newton R, McGuigan M. The effect of accentuated eccentric load on jump kinetics in high-performance volleyball players. *Int J Sports Sci Coaching.* 2007; 2:267-273.
33. OJasto T, Häkkinen K. Effects of different accentuated eccentric loads on acute neuromuscular, growth hormone, and blood lactate responses during a hypertrophie protocol. *J Strength Cond Res.* 2009; 23(3):946-953.
34. Aura O, Komi PV. Effects of prestretch intensity on mechanical efficiency of positive work and on elastic behavior of skeletal muscle in stretch-shortening cycle exercise. *Int J Sports Med.* 1986; 7(3):I37-143.
35. Markovic G, Jaric S. Positive and negative loading and mechanical output in maximum vertical jumping. *Med Sci Sports Exerc*. 2007; 39(10): 1757-64.
36. Aboodarda SJ, Mokhtar AH, Wilson B, Samson M, Byrne J, Behm DG. Does performing drop jumps with additional eccentric loading improve jump performance? *J Strength Cond Res.* 2014; 28(8):2314-23.
37. Bobbert MF, Huijing PA, and Van Ingen Schenau GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. *Med Sci Sports Exerc.* 1987a; 19:332–338.
38. Bobbert MF, Huijing PA, van Ingen Schenau GJ. Drop jumping. II. The influence of dropping height on the biomechanics of drop jumping. *Med Sci Sports Exerc*. 1987b; 19:339–346.
39. Borenstein M, Hedges LV, Higgins P, Rothstein HR. Introduction to metaanalysis. Wiley, 2009.
40. Moore CA, Schilling BK. Theory and application of augmented eccentric loading. *Natl Strength Cond Assoc J*. 2005; 5:20–27.
41. Purves D, Augustine GJ, Fitzpatrick D, Hall WC, L Lamantia A, Mcnamara JO, Williams SM *Neuroscience*. Sinauer Associates, Inc. Sunderland, Massachusetts USA, 3rd edition. 2004.
42. Walshe AD, Wilson GJ, Ettema GJC. Stretch-shortening cycle compared with isometric preload: contribution to enhanced muscular performance. *J Appl Physiol.* 1995; 84:97-106.
43. Bosco C, Viitasalo JT, Komi PV, Luhtanen P Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. *Acta Physiol Scand.* 1982; 4:557-565.
44. Kubo K, Kawakami Y, Fukunaga T. Influence of elastic properties of tendon structures on jump performance in *humans. J Appl Physiol.* 1999; 87:2090-2096.
45. Behm DG. Sale DG. Velocity specificity of resistance training. *Sports Med* 1993; 15:374-88.
46. Behm DG. Neuromuscular implications and applications of resistance training. *J Strength Cond Res.* 1995; 9:264-274.
47. Komi PV and Gollhofer A. Stretch reflexes can have an important role in force enhancement during SSC-exercise. *J Appl Biomech*. 1997; 13: 451–460.
48. Cappa DF, Behm DG. Training specificity of hurdle vs. countermovement jump training. *J Strength Cond Res* 2011; 25(10):2715-20.

49. Cappa DF, Behm DG. Neuromuscular characteristics of drop and hurdle jumps with different types of landings. *J Strength Cond Res*. 2013; 27:3011-20.
50. Ruan M, Li L. Approach run increases preactivation and eccentric phases muscle activity during drop jumps from different drop heights. *J Electrom Kinesiol.* 2010; 20:932–938.
51. Taube W, Leukel C, Lauber B, Gollhofer A. The drop height determines neuromuscular adaptations and changes in jump performance in stretch-shortening cycle training. *Scand J Med Sci Sports* 2012; 22:671–683.
52. Aura O, Viitasalo J. Biomechanical characteristics of jumping. *Int J Sport Biomech* 1989; 5:89–98.
53. Mero A, Komi P. EMG, force and power analysis of sprint specific strength exercises. *J Appl Biomech.* 1994; 10:1–13.
54. Duncan A, McDonagh MJ. Stretch reflex distinguished from pre-programmed muscle activations following landing impacts in man. *J Physiol.* 2000; 526(Pt. 2): 457–468.
55. Liebermann DG, Hoffman JR. Timing of preparatory landing responses as a function of availability of optic flow information. *J Electromyogr Kinesiol.* 2005; 15:120–130.
56. Wilson G, Wood GA, Elliott BC. Optimal stiffness of series elastic component in a stretch-shorten cycle activity. *J Appl Physiol*. 1991; 70:825–833.
57. Gollhofer A, Schmidtblecher D. *Muscle Activation Patterns of Human Leg Extensors and Force-Time Characteristics in Jumping Exercises under Increased Stretching Loads.* Amsterdam: Free University Press, 1988.
58. Komi, PV, Gollhofer A. Stretch reflexes can have an important role in force enhancement during SSC-exercise. *J Appl Biomech* .1997; 13:451–460.
59. Walshe AD, Wilson GJ, Ettema GJ. Stretch-shorten cycle compared with isometric preload: Contributions to enhanced muscular performance. *J Appl Physiol*. 1998; 84:97–106.
60. Fetz EE, Jankowska E, Johannisson T, Lipski J. Autogenetic inhibition of motoneurones by impulses in group Ia muscle spindle afferents. *J Physiol*. 1979; 293:173-95.