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Review

Muscle activation comparisons between elastic and isoinertial resistance: A meta-analysis

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ABSTRACT

Background: Elastic resistance has been commonly used in the therapeutic and fitness setting; however, the ability of elastic resistance to overload and activate muscles has been questioned because of linear increase in elastic resistance as the device is elongated. The purpose of this meta-analysis was to examine the available literature on muscle activation associated with isoinertial and elastic resistance exercises, and to provide a quantitative summary comparing the two resistance training modes.

Methods: In a random-effects model, the Hedge's g effect size was used to calculate the biased corrected standardized mean difference between the elastic and isoinertial resistance activation of prime movers (agonist), antagonists, assistant movers and stabilizer muscles.

Findings: There was a lack of significant difference with the prime movers (effect size = −0.037, confidence interval: −0.202 to 0.128, $p = 0.660$), antagonists (effect size = 0.089, confidence interval: −0.112 to 0.290, $p = 0.385$), synergists (effect size = −0.133, confidence interval: −0.342 to 0.076, $p = 0.213$) and stabilizer (effect size = 0.142, confidence interval: −0.006 to 0.289, $p = 0.060$) muscle electromyography activity recorded during similar exercises using elastic and isoinertial resistance.

Interpretation: Elastic resistance provides similar prime mover, antagonist, assistant movers and stabilizer muscle activation as isoinertial resistance; contradicting the traditional criticism that the elastic band would not elicit comparable levels of muscle activation as isoinertial resistance exercise. Since development of muscle strength is closely related to the duration of muscle tension, relatively equal muscle adaptations could be expected following the two modes of training provided that equal external resistance is employed between the two exercises.

Level of Evidence: 2a

1. Introduction

One of the critical factors for achieving adequate resistance training stimuli is the choice of exercise equipment which plays a significant role in the outcomes associated with training (Kraemer et al., 1998). Elastic resistance (ER) devices (also known as elastic bands, rubber bands and tubing) are widely used in the therapeutic and fitness settings (Andersen et al., 2010; Behm, 1987, 1991; Colado et al., 2010; Hintermeister et al., 1998; Jakobsen et al., 2013; Page and Ellenbecker, 2003; Page et al., 1993; Schulthies et al., 1998). Clinical literature has supported the advantages of rehabilitation training using ER for different types of musculoskeletal conditions including treatment of strength and pain impairment, balance and proprioception enhancement, increasing range of motion (ROM) after trauma and improvement in functional disabilities (Page et al., 1993; Mikesky et al., 1994; Willett et al., 1998; Hopkins et al., 1999; Decker et al., 1999; Matheson et al., 2001; Swanik et al., 2002; Simoneau et al., 2001; Kibler et al., 2001; Myers et al., 2005; Aboodarda et al., 2012; Brandt et al., 2013; Serner et al., 2014; Jensen et al., 2014; Sundstrup et al., 2014). However, it has been noted that the mechanical characteristics of ER may be disadvantageous as ER provides a linear increase in resistance as the device is elongated (Behm, 1988, 1991; Hughes et al., 1999; Simoneau et al., 2001). Theoretically, muscle tension varies according to its length throughout the ROM; this often results in a 'bell-shaped' strength curve as muscles contract through the ROM. With the changing dynamics of the muscle length-tension relationship (Rassier et al., 1999) and the increasing force produced by ER through the ROM as its elongated, the extent of muscle activation during ER exercise may not be similar compared to traditional dynamic constant load exercises (Page and Ellenbecker, 2003). It's important to note that the moment of constant

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load exercises is also variable around a joint axis of rotation, with the peak moment often occurring near mid-range when the muscle is at its greatest mechanical advantage (Baechle and Earle, 2000; Fleck and Kraemer, 2004). Thus, some authors have claimed that ER is not as effective as conventional training devices (e.g. free weight and resistance machines) because of an increase in resistance at the end of the ROM (Anderson et al., 2008; Hostler et al., 2001). However, previous research studies have demonstrated that despite providing an ascending resistance curve, ER device, in conjunction with length of lever arm, offers a bell-shaped torque curve which is compatible with torque generating capability in many human movements (Aboodarda et al., 2013; Hughes et al., 1999; Simoneau et al., 2001).

Therefore, although some investigators have questioned the effectiveness of ER training in generation of adequate muscle activation, there are several lines of evidence that demonstrate no significant difference in electromyographic (EMG) activity level during exercises using ER or conventional devices such as free weights and resistance machines (Aboodarda et al., 2011a, 2011b, 2013; Borreani et al., 2014; Ebben and Jensen, 2002; Jakobsen et al., 2013, 2014; Matheson et al., 2001; Muhitch, 2006). For example, Brandt et al. (2013) did not find any significant differences in EMG activity with hip adduction or abduction exercises resisted with either ER or weight machines for seven hip and lower limb muscles. The one exception to these findings was the greater gluteus medius EMG activity with ER when performing hip abduction contractions. Similarly, Jakobsen et al. (2013, 2014) did not find any difference in EMG activity of seven leg muscles during knee flexion and extension exercises using ER and resistance machines. Contrary to these findings, Andersen et al. (2010) reported lower EMG activity in four muscles (trapezius, deltoid, splenius capitis and extensor digitorum) with ER compared to dumbbells when performing lateral raises and wrist extension exercises at similar intensities. However in the same study, there was greater infraspinatus EMG activity with ER when performing resisted external rotation of the shoulder. In another study by Sundstrup et al. (2014) vastus medialis and lateralis and rectus femoris demonstrated lower EMG during lunge exercises using ER compared to dumbbell, whereas the level of muscle activity did not show any difference for gluteus (maximus and medius) and erector spine muscles. At the same study, biceps femoris showed higher EMG during ER than dumbbell. Hence, the EMG literature is not consistent regarding whether muscle activation is similar or differs between ER and conventional dynamic constant load exercises.

In order to overcome the shortcoming of ER exercises in providing adequate muscle activation at the beginning of concentric phase, Aboodarda et al. (2011a, 2011b, 2013) recommended using additional units of elastic bands in parallel and reducing the initial length of the elastic material (by 30%). They reported greater biceps brachii EMG activity with modified ER compared to dumbbells during an elbow flexion exercise (Aboodarda et al., 2013). These investigators however reported no difference in quadriceps EMG activity between ER and a resistance machine (Nautilus®) during seated knee extension exercise (Aboodarda et al., 2011a, 2011b).

With most free weight and machine resistances devices excluding isokinetic machines, there is a constant resistance to motion with a constant mass whose resistive torque modulates dependent upon the joint angle. Hence, such resistance activities within this review will be labeled as isoinertial resistance (IR) (Abernethy et al., 1995). Both ER and IR have been shown to be effective for promoting strength gains throughout the lifespan (Behm, 1991, 1995; Calatayud et al., 2015; Colado and Triplett, 2008) as training-induced enhancements in muscle strength can involve neural and morphological adaptations (Behm, 1995; Kraemer et al., 1998; Sale, 1988), it is important to know whether the muscle activation associated with ER exercises is generally similar or differs from IR exercises. Therefore, the purpose of this meta-analysis was to examine the available literature on EMG activity with ER and IR to provide a quantitative comparison of these two ubiquitous training methods for health, rehabilitation and athletic training.

2. Methods

2.1. Search strategy and inclusion/exclusion criteria

This review included studies that directly compared the effect of ER and IR exercises on EMG activity. 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, exercise cord, Thera-Band, theraband, elastic resistance training, elastic band exercises, isoinertial exercise, isotonic contractions, and electromyography. All references from the selected articles were also crosschecked manually by the authors to identify relevant studies that might have been missed in the search and to eliminate duplicates.

2.2. Inclusion criteria (study selection)

Studies comparing the effect of ER and IR on EMG activity as a measure of muscle activation were included in the review if they fulfilled the following selection criteria: the study 1) directly compared EMG activity of muscles involved with dynamic limb movements resisted with ER and free weights or resistance machines (IR); 2) EMG was recorded during the same motion (e.g. biceps curl) and the same phase of contraction (e.g. concentric phase), so the only difference between the two mode of exercise was the external resistance (ER vs. IR) 3) used healthy, active human subjects; 4) was written in English and published prior to November 2015; and 5) was published in a peer-reviewed journal (abstracts and unpublished studies were excluded). Studies were excluded if 1) EMG activity elicited from ER was not directly compared to activity associated with IR, and 2) different resistance intensities were used in the two modes of exercise (although the magnitude of external force between the two modes of exercise (ER and IR) was not equalized in a standardized fashion in all experiments; however, the investigators of the included studies indicated the tensile resistance of ER was purposefully selected to match the IR load). This resulted in 18 applicable studies (Fig. 1).

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 and IR muscle activation levels. A random effect model was used because the relative weight assigned to each of the studies has less impact on computed combined effect size. In other words, in the fixed effect model, one or two studies with relatively high weight can shift the combined effect size and associated confidence intervals in one particular direction, whereas in a random effect model this issue is moderated. In studies where the EMG of multiple muscle groups was reported, the tested muscles were categorized to prime mover, assistant (synergist) mover, antagonist, and stabilizer based on the responsibility of the corresponding muscle in the exercise. Muscle categorization was performed based on the following definitions provided by Hamill and Knutzen (1995): Prime movers: the muscles which are primarily responsible for producing a given movement; Assistant movers: the muscles which contract to assist the prime movers if more force is required; Antagonists: muscles opposing or producing the opposite joint movement as prime movers; Stabilizers: muscles which act in one segment so that a specific movement in an adjacent joint can occur. Separate meta-analysis was performed for each category of the muscles (four separate meta-analyses were conducted for prime movers, assistant movers, antagonists, and stabilizers). It is worth noting that every documented experiment could be influenced by a degree of sampling error. Employing more than one data point from a certain study (e.g. more than one prime mover muscle EMG) could increase the likelihood of bias in overall effect size. To minimize the contribution of sampling error, only one ES from every study

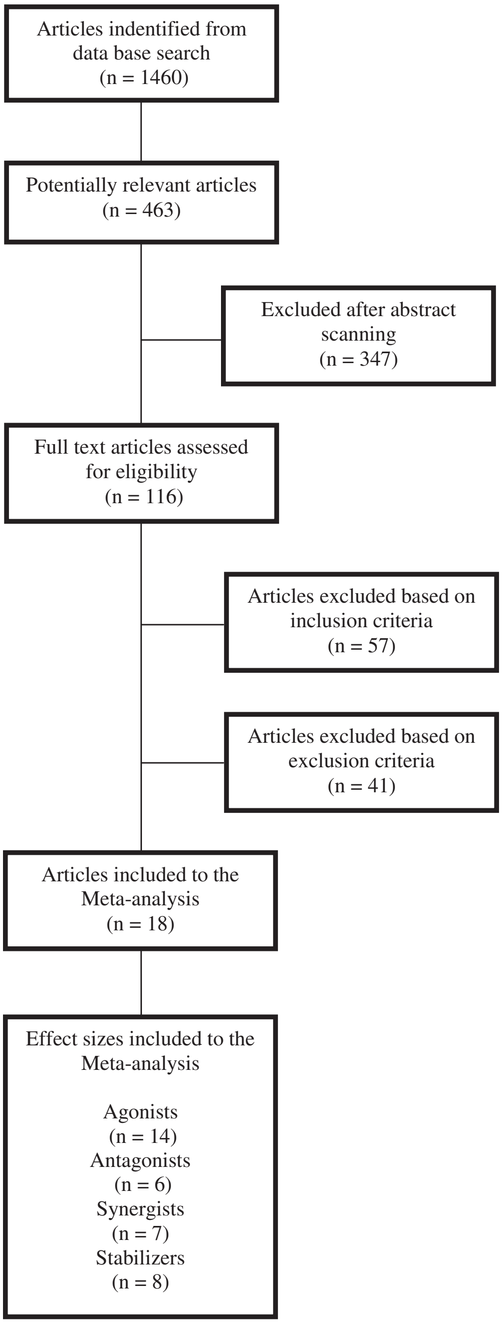


Fig. 1. Flow diagram: study selection/inclusion process.

was employed in the meta-analysis. Thus, in the cases that two or more muscles were identified (e.g. as prime movers in one study), an average of reported EMG values were used for effect size analysis. ES were calculated to evaluate the magnitude of the difference between ER and IR according to the criterion of 0.80 large; 0.50 medium and 0.20 small (Cohen and Hillside, 1988). The Hedges's g ES and 95% CIs for the outcomes of each study were illustrated with 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 of 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 (Borenstein et al., 2009). Publication bias was calculated based on the funnel plot method recommended by Van Rhee et al. (2015). The distribution of the estimated effect size (Hedges's g ES) for each study (on x-axis) and standard error (on y-axis) were used to calculate the measure. In this technique the combined effect size (and the corresponding confidence interval) as well as the number of missing studies are calculated (Duval and Tweedie, 2000a, 2000b). The publication bias was calculated for the prime movers data pool because it was the most comprehensive data set among the four muscle groups with 14 studies (Table 1).

3. Results

3.1. Prime mover EMG

Fourteen studies that quantified and compared primary mover muscles (agonists) EMG activity with exercises using ER and IR met the inclusion criteria of the meta-analysis (Fig. 2). The overall effect obtained from 354 untrained or recreationally active participants (181 males and 173 female) demonstrated that there was no significant difference in computed combined effect size EMG activity between ER and IR exercises (Hedges's g ES $= -0.037$, CI: -0.202 to 0.128, $p = 0.660$) (Fig. 2). The test of heterogeneity indicated that there was no significant difference between estimates (effect sizes) derived from the 14 studies (Q-value $= 15.3$, $p = 0.283$, $I^2 = 15.031$). In fact, 28% of the inter-study variation in ES presented in Fig. 2 was due to factors such as different experimental protocols, tested muscle groups and/or sampling error and not due to real treatment effect (ER and IR). The small effect size and large confidence intervals derived from each experiment supported the idea that ER and IR exercises produced similar muscle activity in prime movers. However, due to small sample sizes used in majority of the studies presented in Fig. 2, the large confidence intervals for the reviewed studies point out to a low precision of estimate as well.

3.2. Antagonist EMG

Six studies, which quantified and compared antagonist muscle EMG activity with exercises using ER and IR, met the inclusion criteria (Fig. 3). The overall effect obtained from 144 untrained or recreationally active participants (85 males and 59 female) indicated that there was no difference in the antagonist muscle EMG during ER compared to IR exercises (Hedges's g ES $= 0.089$, CI: -0.112 to 0.290, $p = 0.385$) (Fig. 3). The test of heterogeneity also showed no significant difference between estimates (effect sizes) derived from the 6 studies (Q-value $= 5.017$, $p = 0.542$, $I^2 < 0.001$). More specifically, 54% of observed difference between studies was due to sampling error. This notion is evident in the small I^2 observed for the overall estimate (I^2 determines what proportion of the observed difference between studies is due to treatment effect and what proportion could be attributed to sampling error).

3.3. Stabilizer EMG

Thirteen studies met the inclusion criteria (Fig. 4). The overall effect obtained from 344 untrained or recreationally active participants (135 males and 209 female) demonstrated a trivial effect (Hedges's g ES $= 0.142$, CI: -0.006 to 0.289, $p = 0.060$) for stabilizers muscle EMG activity comparing ER and IR conditions (Fig. 4). There was very small inter-study variation between different estimates, which suggest that there was no heterogeneity between effect sizes derived from the 13 studies (Q-value $= 4.768$, $p = 0.968$, $I^2 < 0.001$).

3.4. Assistant mover EMG

Seven studies met the inclusion criteria (Fig. 5). The overall effect obtained from 184 untrained or recreationally active participants (81 males and 103 female) demonstrated that there was no significant difference in assistant mover (synergist) muscle EMG activity between ER and IR exercises (Hedges's g ES $= -0.133$, CI: -0.342 to 0.076,

Table 1
Details of the studies used in the meta-analysis. CI: confidence intervals, EMG: electromyography, E0: elastic band with slack initial length, E30: elastic band with 30% reduced initial length, F: female, M: male, mV: microvolt, MVC: maximum voluntary isometric contraction, NrmsEMG: normalized root mean square EMG RM: repetition maximum, RT: recreationally trained, SD: standard deviation.

Authors/year	“n” (M/F)	Age	Population	Exercises	Muscles tested	Muscle role classification	Bands EMG	Bands SD	Isoinertial EMG	Isoinertial SD	*p* value
Aboodarda et al. (2013)	10M, 6F	24.4, 27.2	Recreationally active	8 RM biceps curl	Biceps brachii (% MVC) E0	Agonist	53.45	19.71	54.90	18.26	>0.05
					Biceps brachii (% MVC) E30	Agonist	61.93	19.98	54.90	18.26	0.001
Aboodarda et al., 2011a (2011b)	9M, 7F	24.0, 22.4	Inexperienced RT	8 RM knee extension	Quadriceps (% MVC) E0	Agonist	52.82	6.78	64.06	7.51	<0.05
					Quadriceps (% MVC) E30	Agonist	65.37	7.38	64.06	7.51	>0.05
Andersen et al. (2010)	16F	41.9 (26–55)	Workers	Lateral raise: 3 repetitions	Trapezius (% MVC)	Stabilizer	83.00	12.40	84.00	12.00	0.0001
					Deltoid (% MVC)	Agonist	82.00	12.00	88.00	10.00	0.0001
					Splenius capitis (% MVC)	Stabilizer	58.00	18.40	62.00	21.20	0.0001
				Wrist extension	Extensor digitorum (% MVC)	Agonist	50.00	17.20	61.00	16.00	0.0001
				Shoulder external rotation	Infraspinatus (% MVC)	Agonist	36.00	16.00	42.00	16.80	0.0001
Bellew et al. (2010)	10M, 10F	24.8 (22 − 30)	Recreationally active	Heel raise	Peroneus longus (mV)	Agonist	319.20	649.04	296.30	494.38	0.08
Borreani et al. (2014)	24M, 20F	22.6, 23.6	RT min 1 year	Squat at 140°	Tibialis anterior (% MVC)	Stabilizer	30.10	11.21	29.38	14.33	
					Peroneus longus (% MVC)	Stabilizer	30.10	11.21	29.36	0.66	<0.05
					Soleus (% MVC)	Stabilizer	22.29	6.77	22.01	0.73	<0.05
Brandt et al. (2013)	16F	45.7	Untrained	Hip abduction	Rectus femoris (% MVC)	Stabilizer	57.00	20.00	52.00	20.00	>0.05
					Vastus lateralis (% MVC)	Stabilizer	18.00	20.00	29.00	20.00	>0.05
					Vastus medialis (% MVC)	Stabilizer	16.00	16.00	27.00	20.00	>0.05
					Biceps femoris (% MVC)	Stabilizer	13.00	4.00	10.00	4.00	>0.05
					Semitendinosus (% MVC)	Stabilizer	11.00	4.00	13.00	4.00	>0.05
					Gluteus medius (% MVC)	Agonist	101.00	28.00	80.00	32.00	0.0001
					Adductor longus	Antagonist	14.00	8.00	7.00	8.00	>0.05
				Hip adduction	Rectus femoris (% MVC)	Stabilizer	25.00	8.00	14.00	8.00	>0.05
					Vastus lateralis (% MVC)	Stabilizer	26.00	16.00	13.00	8.00	>0.05
					Vastus medialis (% MVC)	Stabilizer	23.00	16.00	17.00	12.00	>0.05
					Biceps femoris (% MVC)	Stabilizer	38.00	20.00	39.00	12.00	>0.05
					Semitendinosus (% MVC)	Stabilizer	49.00	24.00	41.00	12.00	>0.05
					Gluteus medius (% MVC)	Antagonist	40.00	36.00	31.00	24.00	>0.05
					Adductor longus (% MVC)	Agonist	63.00	32.00	82.00	20.00	0.07
Ebben and Jensen (2002)	5M, 6F	19.4, 19.1	NCAA athletes	Squats 3rd rep of 5 RM		Agonist	0.94	0.20	0.96	0.31	>0.05
					Quadriceps: concentric (Volts)	Agonist	0.89	0.23	0.91	0.19	>0.05
					Quadriceps: concentric (Volts)	Antagonist	0.58	0.25	0.62	0.25	>0.05
					Hamstrings: concentric (Volts)	Antagonist	0.47	0.16	0.53	0.20	>0.05
					Hamstrings: concentric (Volts)						
Hughes and McBride (2005)	7M , 5F	29.7									
				External rotation	Posterior deltoid (% MVC)	Agonist	55.00	34.64	80.00	34.64	<0.05
					Infraspinatus (% MVC)	Synergist	95.00	34.64	85.00	34.64	>0.05
				Full can exercise	Upper trapezius/supraspinatus (% MVC)	Synergist	135.00	103.92	110.00	86.60	<0.05
					Infraspinatus (% MVC)	Stabilizer	70.00	34.64	60.00	34.64	<0.05
				Retraction exercise	Posterior deltoid (% MVC)	Stabilizer	100.00	34.64	150.00	34.64	<0.05
					Infraspinatus (% MVC)	Stabilizer	35.00	34.64	50.00	34.64	<0.05
				Extension exercise	Latissimus dorsi (% MVC)	Synergist	75.00	34.64	85.00	34.64	<0.05

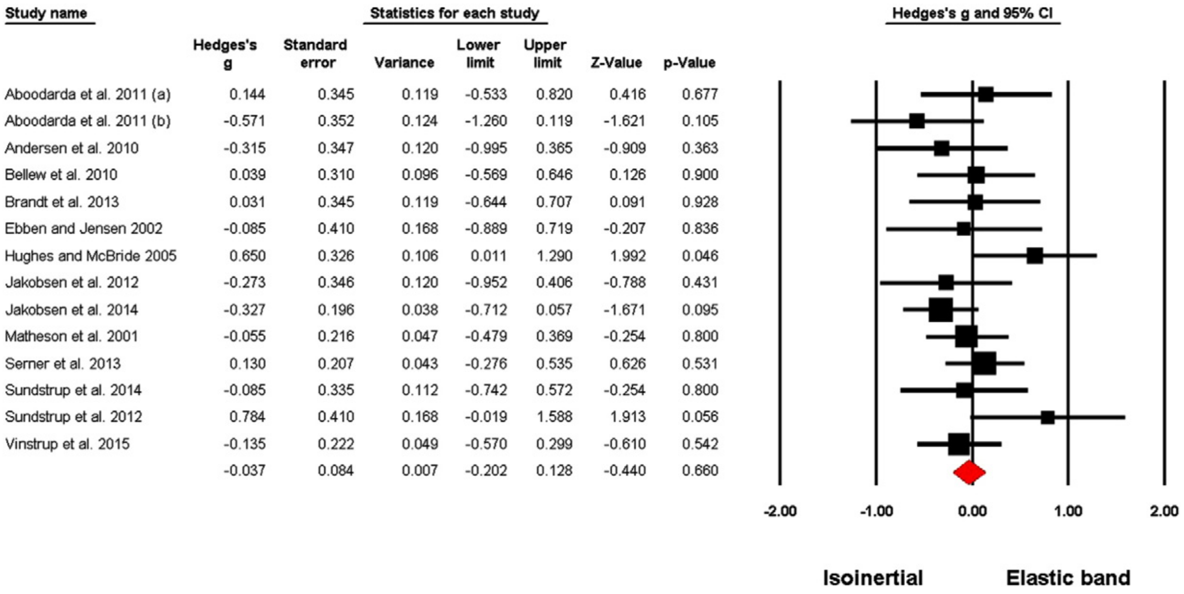
(continued on next page)

Table 1 (*continued*)

Authors/year	"n" (M/F)	Age	Population	Exercises	Muscles tested	Muscle role classification	Bands EMG	Bands SD	Isoinertial EMG	Isoinertial SD	*p* value
					Posterior deltoid (% MVC)	Synergist	110.00	69.28	108.00	69.28	>0.05
Jakobsen et al. (2014)	13M, 6F	39, 42 (28–67)	Untrained	Hamstring curl	Biceps femoris (% MVC)	Agonist	80.80	24.79	83.00	25.23	>0.05
					Semitendinosus (% MVC)	Agonist	78.90	24.79	92.40	25.23	>0.05
					Adductors (% MVC)	Synergist	82.30	24.79	82.20	25.23	>0.05
					Gluteus medius (% MVC)	Stabilizer	29.50	24.79	17.80	25.23	>0.05
					Rectus femoris (% MVC)	Antagonist	6.00	24.79	5.30	25.23	>0.05
					Vastus lateralis (% MVC)	Antagonist	8.60	24.79	4.30	25.23	>0.05
					Vastus medialis (% MVC)	Antagonist	10.10	24.79	9.90	25.23	>0.05
Jakobsen et al. (2013)	9M, 7F	41, 44 (28–67)	Untrained	Leg extension	Rectus femoris (% MVC)	Synergist	76.70	20.01	83.90	20.01	>0.05
					Vastus lateralis (% MVC)	Agonist	83.70	20.01	84.70	20.01	>0.05
					Vastus medialis (% MVC)	Agonist	71.50	20.01	81.80	20.01	>0.05
					Adductors (% MVC)	Stabilizer	17.20	19.57	20.20	20.01	>0.05
					Gluteus medius (% MVC)	Stabilizer	13.20	19.57	13.20	20.01	>0.05
					Biceps femoris (% MVC)	Antagonist	13.60	19.57	17.30	20.01	>0.05
					Semitendinosus (% MVC)	Antagonist	7.90	19.57	7.30	20.01	>0.05
Lister et al. (2007)	15M, 15F	20.0 ± 1.7	Intercollegiate athletes	Shoulder flexion	Upper trapezius (NrmsEMG)	Stabilizer	0.41	0.35	0.37	0.23	$p <$ 0.0001
					Lower trapezius (NrmsEMG)	Stabilizer	0.50	0.40	0.39	0.28	$p <$ 0.0001
					Serratus anterior (NrmsEMG)	Stabilizer	0.82	0.52	0.62	0.36	$p <$ 0.0001
Matheson et al. (2001)	17M, 35F	23.5	University students	Seated quadriceps exercise	Rectus femoris (% MVC)	Agonist	27.70	17.70	29.90	17.30	>0.05
					Vastus lateralis (% MVC)	Agonist	41.40	16.50	40.50	17.00	>0.05
					Vastus medialis (% MVC)	Agonist	38.40	16.60	40.20	18.90	>0.05
Saeterbakken et al. (2014)	25F	24.3 ± 4.9	Recreationally active	6 RM squats	Erector spinae (mV)	Stabilizer	0.21	0.10	0.21	0.10	0.66
					External oblique (mV)	Stabilizer	0.06	0.08	0.06	0.05	0.608
					Rectus abdominis (mV)	Stabilizer	0.06	0.08	0.06	0.07	0.585
Serner et al. (2014)	40M	21.4 ± 3.3	Soccer players	Hip adduction	Adductor longus (% MVC)	Agonist	103.00	37.95	99.00	20.78	>0.05
					Gluteus medius (% MVC)	Antagonist	18.00	18.97	12.00	10.39	>0.05
					Rectus abdominis (% MVC)	Stabilizer	18.00	18.97	15.00	10.39	>0.05
					External abdominal oblique (% MVC)	Stabilizer	9.00	18.97	11.00	10.39	>0.05
Sundstrup et al. (2012)	18M, 24F	28–67	Untrained	Abdominal crunches	Rectus abdominis (% MVC)	Agonist	104.00	24.62	84.00	24.62	0.0001
					External oblique (left) (% MVC)	Synergist	86.00	23.97	79.00	24.62	>0.05
					External oblique (right) (% MVC)	Synergist	79.00	24.62	71.00	24.62	>0.05
					Erector spinae (left) (% MVC)	Antagonist	12.00	31.10	20.00	31.10	>0.05
					Erector spinae (right) (% MVC)	Antagonist	11.00	29.16	14.00	30.45	>0.05
					Gluteus medius (% MVC)	Stabilizer	19.00	23.97	15.00	24.62	>0.05
					Gluteus maximus (% MVC)	Stabilizer	10.00	24.62	5.00	24.62	>0.05
					Rectus femoris (% MVC)	Synergist	27.00	23.97	65.00	24.62	0.0001
					Vastus medialis (% MVC)	Stabilizer	22.00	23.97	25.00	24.62	>0.05
					Vastus lateralis (% MVC)	Stabilizer	16.00	23.97	23.00	24.62	>0.05
					Biceps femoris (% MVC)	Stabilizer	10.00	23.97	5.00	24.62	>0.05
					Semitendinosus (% MVC)	Stabilizer	11.00	23.97	4.00	24.62	>0.05
					Adductor (% MVC)	Stabilizer	19.00	24.62	14.00	24.62	>0.05
Sundstrup et al.	18M,	37–45	Untrained	Lunges	Vastus medialis (ECC)	Antagonist	77.00	31.86	93.00	31.86	0.001

Table 1 (*continued*)

Authors/year	"n" (M/F)	Age	Population	Exercises	Muscles tested	Muscle role classification	Bands EMG	Bands SD	Isoinertial EMG	Isoinertial SD	*p* value
(2014)	28F		adults		(% MVC)						
					Vastus lateralis (ECC) (% MVC)	Antagonist	71.00	31.18	84.00	32.54	0.01
					Rectus femoris (ECC) (% MVC)	Synergist	46.00	31.86	62.00	31.86	0.001
					Gluteus medius (ECC) (% MVC)	Stabilizer	45.00	31.18	46.00	32.54	>0.05
					Gluteus maximus (ECC) (% MVC)	Stabilizer	42.00	31.86	38.00	31.86	>0.05
					Erector spinae (left) (ECC) (% MVC)	Stabilizer	41.00	31.18	32.00	31.86	>0.05
					Erector spinae (right) (ECC) (% MVC)	Stabilizer	43.00	31.18	36.00	31.86	>0.05
					Biceps femoris (ECC) (% MVC)	Agonist	38.00	31.18	23.00	31.86	0.01
					Semitendinosus (ECC) (% MVC)	Agonist	28.00	31.18	16.00	31.18	>0.05
					Adductor (ECC) (% MVC)	Stabilizer	35.00	31.18	41.00	31.86	>0.05
					Vastus medialis (CON) (% MVC)	Agonist	83.00	37.29	94.00	37.96	>0.05
					Vastus lateralis (CON) (% MVC)	Agonist	80.00	37.29	85.00	38.64	>0.05
					Rectus femoris (CON) (% MVC)	Synergist	51.00	37.29	61.00	37.96	>0.05
					Gluteus medius (CON) (% MVC)	Stabilizer	66.00	37.29	56.00	38.64	>0.05
					Gluteus maximus (CON) (% MVC)	Stabilizer	63.00	37.29	48.00	37.96	0.01
					Erector spinae (left) (CON) (% MVC)	Stabilizer	57.00	37.29	37.00	37.96	0.001
					Erector spinae (right) (CON) (% MVC)	Stabilizer	58.00	37.29	41.00	37.29	0.01
					Biceps femoris (CON) (% MVC)	Antagonist	50.00	37.29	29.00	37.29	0.0001
					Semitendinosus (CON) (% MVC)	Antagonist	38.00	37.29	19.00	37.29	0.001
					Adductor (CON) (% MVC)	Stabilizer	36.00	37.29	40.00	37.96	>0.05
Vinstrup et al. (2015)	17M	41 (26–67)	Healthy and untrained	Torso-twists	Rectus abdominis (% MVC)	Synergist	10.00	CI = (−3 to 24)	16.00	CI = (3 to 29)	0.45
					External obliques (left) (% MVC)	Agonist	54.00	(40 to 67)	77.00	(64 to 90)	0.0018
					External obliques (right) (% MVC)	Agonist	47.00	(34 to 60)	41.00	(28 to 54)	0.39
					Erector spinae (left) (% MVC)	Stabilizer	24.00	(10 to 37)	18.00	(4 to 32)	0.47
					Erector spinae (right) (% MVC)	Stabilizer	50.00	(36 to 64)	32.00	(18 to 46)	0.03
Witt et al. (2011)	6M, 15F	25.3 (21–37)	Healthy and untrained	Diagonal internal and external flexions	Diagonal internal flexion (% MVC)						
					Upper trapezius (% MVC)	Stabilizer	53.00	136.02	39.60	120.91	>0.05
					Middle trapezius (% MVC)	Stabilizer	16.70	68.70	18.40	71.44	>0.05
					Lower trapezius (% MVC)	Stabilizer	23.90	74.65	23.70	84.27	>0.05
					Serratus anterior (% MVC)	Stabilizer	50.00	128.69	43.70	103.96	>0.05
					Diagonal external flexion (% MVC)						
					Upper trapezius (% MVC)	Stabilizer	68.50	219.38	53.20	181.80	>0.05
					Middle trapezius (% MVC)	Stabilizer	45.30	94.80	33.20	67.32	>0.05
					Lower trapezius (% MVC)	Stabilizer	44.90	142.89	32.00	63.66	>0.05
					Serratus anterior (% MVC)	Stabilizer	48.70	98.92	44.60	98.92	>0.05



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aboodarda et al. 2011 (a)	0.144	0.345	0.119	-0.533	0.820	0.416	0.677
Aboodarda et al. 2011 (b)	-0.571	0.352	0.124	-1.260	0.119	-1.621	0.105
Andersen et al. 2010	-0.315	0.347	0.120	-0.995	0.365	-0.909	0.363
Bellew et al. 2010	0.039	0.310	0.096	-0.569	0.646	0.126	0.900
Brandt et al. 2013	0.031	0.345	0.119	-0.644	0.707	0.091	0.928
Ebben and Jensen 2002	-0.085	0.410	0.168	-0.889	0.719	-0.207	0.836
Hughes and McBride 2005	0.650	0.326	0.106	0.011	1.290	1.992	0.046
Jakobsen et al. 2012	-0.273	0.346	0.120	-0.952	0.406	-0.788	0.431
Jakobsen et al. 2014	-0.327	0.196	0.038	-0.712	0.057	-1.671	0.095
Matheson et al. 2001	-0.055	0.216	0.047	-0.479	0.369	-0.254	0.800
Serner et al. 2013	0.130	0.207	0.043	-0.276	0.535	0.626	0.531
Sundstrup et al. 2014	-0.085	0.335	0.112	-0.742	0.572	-0.254	0.800
Sundstrup et al. 2012	0.784	0.410	0.168	-0.019	1.588	1.913	0.056
Vinstrup et al. 2015	-0.135	0.222	0.049	-0.570	0.299	-0.610	0.542
	-0.037	0.084	0.007	-0.202	0.128	-0.440	0.660

Fig. 2. Forest plot presenting the results of the Hedges's g ES and 95% CIs for the EMG of the prime mover muscles. Fourteen effect sizes were included to the analysis. 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.

$p = 0.213$) (Fig. 5). There was very small inter-study variation between different estimates, which suggest that there was no heterogeneity between effect sizes derived from the included studies (Q-value = 4.881, $p < 0.559$, $I^2 < 0.001$).

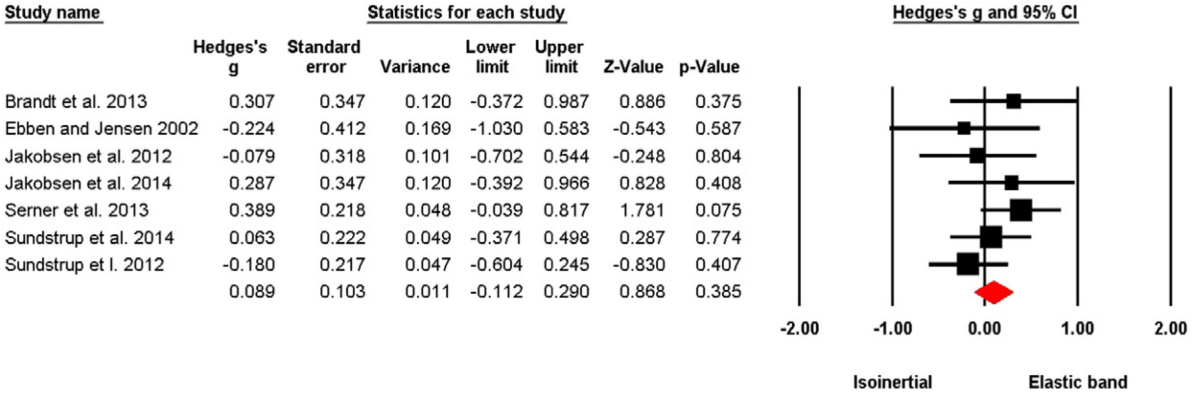
3.5. Publication bias

The effect sizes of 14 studies plotted in Fig. 6 demonstrated a symmetric funnel plot, which indicate fairly equal distribution of the studies along the horizontal line (Hedges's g). Furthermore, the trim-and-fill analysis (Duval and Tweedie, 2000a, 2000b) indicated that the number of missing studies in the meta-analysis on the left or right side of the combined effect size was zero, which suggests that there was little possibility of publication bias for this measure.

4. Discussion

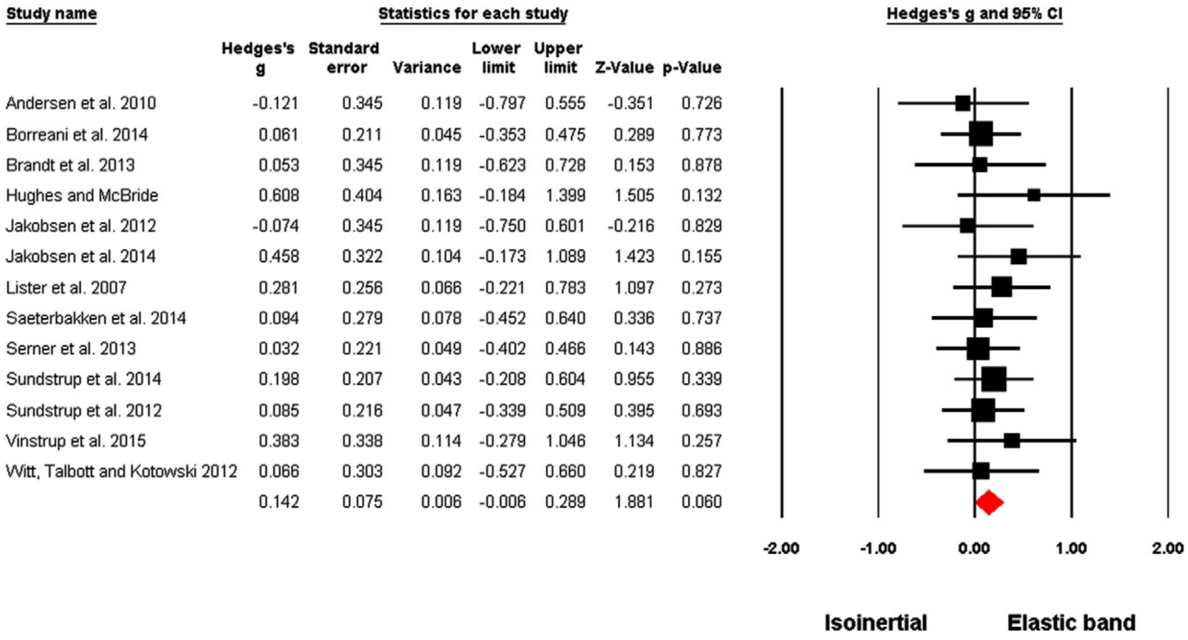
The traditional contention against using elastic bands for resistance training is that ER may not generate adequate muscle activation in the exercising muscles. However, the results of the current meta-analysis demonstrated the lack of significant difference with the prime movers, antagonists, stabilizers and assistant movers EMG activity when comparing ER and IR exercises. Although these finding suggested that ER may produce comparable muscle activation in exercising muscles (compared to IR), it is worth noting that the combined effect size analysis in the current review was performed based on the overall EMG activity measured across the entire range of motion. Considering the differences in pattern of provided external force between ER (i.e. generating more force as elastic band is elongated) and IR (i.e. constant force), more studies are required to quantify and compare EMG activity during different segments of concentric and eccentric phases of motion.

In a study by Aboodarda et al. (2013), the resultant muscle torque and EMG pattern were quantified and compared when performing 8 repetitions maximum (8 RM) biceps curl using ER and IR. They partitioned the concentric and eccentric phases into 6 segments (3 concentric and 3 eccentric phases). Their findings supported the idea that although elastic force increased with elongation, the interaction effects of leverage systems and the muscle length-tension relationship created an ascending-descending torque curve which was compatible with torque generating capability in the elbow flexors. In fact, the moment arm length (horizontal distance from line of action of elastic device to the elbow joint) was shorter at the beginning and end of the concentric phase (compared with mid-concentric phase), which would create a bell-shaped torque curve with the elastic device making the lifting motion easier even at the end of concentric phase when ER was at the highest resistance curve (Hughes et al., 1999). When EMG and muscle



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Brandt et al. 2013	0.307	0.347	0.120	-0.372	0.987	0.886	0.375
Ebben and Jensen 2002	-0.224	0.412	0.169	-1.030	0.583	-0.543	0.587
Jakobsen et al. 2012	-0.079	0.318	0.101	-0.702	0.544	-0.248	0.804
Jakobsen et al. 2014	0.287	0.347	0.120	-0.392	0.966	0.828	0.408
Serner et al. 2013	0.389	0.218	0.048	-0.039	0.817	1.781	0.075
Sundstrup et al. 2014	0.063	0.222	0.049	-0.371	0.498	0.287	0.774
Sundstrup et l. 2012	-0.180	0.217	0.047	-0.604	0.245	-0.830	0.407
	0.089	0.103	0.011	-0.112	0.290	0.868	0.385

Fig. 3. Forest plot presenting the results of the Hedges's g ES and 95% CIs for the EMG of the antagonist muscles. Six effect sizes were included to the analysis. 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.



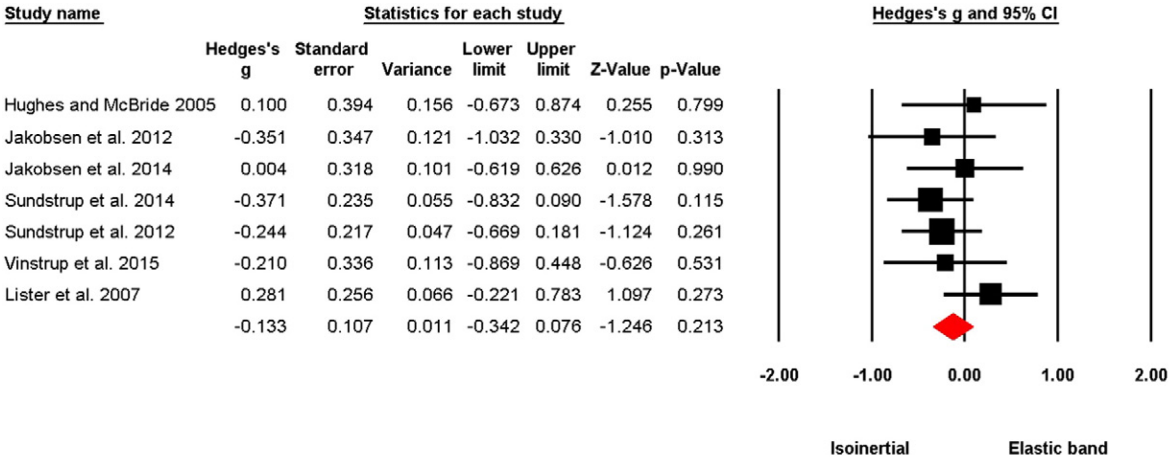
Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Andersen et al. 2010	-0.121	0.345	0.119	-0.797	0.555	-0.351	0.726
Borreani et al. 2014	0.061	0.211	0.045	-0.353	0.475	0.289	0.773
Brandt et al. 2013	0.053	0.345	0.119	-0.623	0.728	0.153	0.878
Hughes and McBride	0.608	0.404	0.163	-0.184	1.399	1.505	0.132
Jakobsen et al. 2012	-0.074	0.345	0.119	-0.750	0.601	-0.216	0.829
Jakobsen et al. 2014	0.458	0.322	0.104	-0.173	1.089	1.423	0.155
Lister et al. 2007	0.281	0.256	0.066	-0.221	0.783	1.097	0.273
Saeterbakken et al. 2014	0.094	0.279	0.078	-0.452	0.640	0.336	0.737
Serner et al. 2013	0.032	0.221	0.049	-0.402	0.466	0.143	0.886
Sundstrup et al. 2014	0.198	0.207	0.043	-0.208	0.604	0.955	0.339
Sundstrup et al. 2012	0.085	0.216	0.047	-0.339	0.509	0.395	0.693
Vinstrup et al. 2015	0.383	0.338	0.114	-0.279	1.046	1.134	0.257
Witt, Talbott and Kotowski 2012	0.066	0.303	0.092	-0.527	0.660	0.219	0.827
	0.142	0.075	0.006	-0.006	0.289	1.881	0.060

Fig. 4. Forest plot presenting the results of the Hedges's g ES and 95% CIs for the EMG of the stabilizer muscles. Eight effect sizes were included to the analysis. 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.

torque was quantified across entire ROM (average of concentric and eccentric phases), the modified ER exercise (i.e. ER device shortened by 30% of the original length (E30)) could result in approximately 15% higher total EMG and 17% higher muscle torque (N.m) than dumbbells (Aboodarda et al., 2013). These findings supported the contention that an ER device has the capacity to provide an appropriate resistance to generate adequate muscle activation in a given muscle.

Elastic band is not the only form of resistance training with variable force or torque through the full ROM. A counter argument could be made that IR resistance is greatest at the start of the ROM due to inertia and decreases towards the end of the ROM due to momentum. Whereas the momentum can be minimized with slower angular velocities, training for power (e.g. cleans, snatches) would generate substantial momentum and thus less resistance towards the end of the ROM. However, there are no reports of angle specific deficits with isoinertial power training. Furthermore, similar to elastic bands, there are many IR exercises (e.g. biceps curls, shoulder abduction, knee extension) that develop less torque at the start of the ROM compared to the mid-range. For example, when performing an isoinertial biceps curl, the external resistance at the start of the movement is at a shorter distance from the axis of rotation (lower torque) than when moving through the mid-range of the ROM (higher torque). Thus in contrast to the training angle specificity (Behm, 1995; Sale, 1988) associated with isometric contractions, dynamic contractions involving free weights, machines or elastic bands seem to have a more generalized training response with insignificant EMG differences with the prime movers (agonist), antagonists, stabilizer and synergists muscle EMG activity when comparing ER and IR exercises.

Theoretically, developing muscle strength has been closely related to the force application and duration of muscle tension (Hortobagyi et al., 1996; Kraemer et al., 2009; Linnamo et al., 2005). Although some investigators have questioned the assumption that the muscle activation assessed by surface EMG is not directly associated to muscle strength development (Edwards and Lippold, 1956; Enoka and Duchateau, 2015), the initial gains in muscle strength following resistance training are primarily attributed to a greater neural activation followed by subsequent strength gains associated with muscle hypertrophy (Moritani et al., 1982; Sale, 1988). The results of current meta-analysis indicating



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Hughes and McBride 2005	0.100	0.394	0.156	-0.673	0.874	0.255	0.799
Jakobsen et al. 2012	-0.351	0.347	0.121	-1.032	0.330	-1.010	0.313
Jakobsen et al. 2014	0.004	0.318	0.101	-0.619	0.626	0.012	0.990
Sundstrup et al. 2014	-0.371	0.235	0.055	-0.832	0.090	-1.578	0.115
Sundstrup et al. 2012	-0.244	0.217	0.047	-0.669	0.181	-1.124	0.261
Vinstrup et al. 2015	-0.210	0.336	0.113	-0.869	0.448	-0.626	0.531
Lister et al. 2007	0.281	0.256	0.066	-0.221	0.783	1.097	0.273
	-0.133	0.107	0.011	-0.342	0.076	-1.246	0.213

Fig. 5. Forest plot presenting the results of the Hedges's g ES and 95% CIs for the EMG of the assistant mover muscles. Seven effect sizes were included to the analysis. 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.

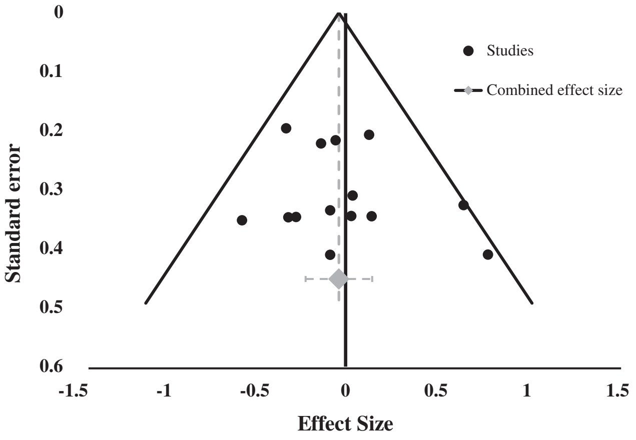


Fig. 6. Funnel plot presenting the distribution of the estimated effect sizes calculated for 14 studies reported prime mover muscles. The Hedges's g ES (on x-axis) and standard error (on y-axis) were used to calculate the publication bias for the current meta-analysis. The combined effect size (the gray diamond) and the corresponding confidence interval (the gray horizontal dash line) are shown in the figure. The symmetric feature of the funnel plot indicates that there is a fairly equal distribution of the studies along the horizontal line with little possibility of publication bias for this measure.

equal EMG activity in prime movers, antagonists, stabilizers and synergists during exercises using ER and IR devices suggest that relatively equal muscle adaptations could be expected following the two modes of training provided that equal external resistance is employed between the ER and IR exercises. This notion was supported by Behm (1991), who demonstrated similar training adaptations following ER and IR exercises. Subjects trained with a shoulder press exercise for 10 weeks either with surgical tubing, Hydragym (uses hydraulic pistons to simulate isokinetic contractions) or isoinertial (Universal® gym) equipment. Although it was hypothesized that there would be angle and velocity specific strength training adaptations, he found similar improvements in torque when shoulder muscles were tested on a Cybex isokinetic dynamometer at 30° and 90° of shoulder abduction as well as when tested at angular velocities of 1.04, 2.09 and 3.14 $\text{rads}\cdot\text{s}^{-1}$. In another study by Aboodarda et al. (2011a) although the overall applied force (across 5 sets of 8 repetition maximum knee extensions) was significantly higher with Nautilus machine resistance compared with elastic bands, the total EMG (5 sets × 8 repetition maximum knee extensions) demonstrated an equal overall muscle activity between ER and Nautilus machine. In addition, muscle damage indicators (T2 relaxation time, delayed onset muscle soreness, MVC and creatine kinase) exhibited similar responses across both modes of training suggesting that both training modes provided a similar training stress, despite lower overall external force generation with elastic bands (Aboodarda et al., 2011b). ER also provides additional unique training features including: ability to perform exercises similar to a sport specific pattern (Jakubiak and Saunders, 2008; Page et al., 1993), providing eccentric and concentric resistance regardless of gravity (Hodges, 2006; Hughes et al., 1999), and ability to perform quick motion and change the direction (Cronin et al., 2003; Wallace et al., 2006).

When comparing muscle activation with ER and IR, it's important to ensure exercise intensities are similar between conditions. Since it's difficult to quantify the exact resistance level of ER due to its linearly increasing resistance, researchers use the rating of perceived exertion (RPE) to match exercise intensities (Andersen et al., 2010; Brandt et al., 2013). In a 12-week training study, Colado and Triplett (2008) compared 3 groups of middle-aged untrained women: TheraBand resistance, isoinertial weight machines, and sedentary control. The training groups performed similar exercise movements using their respective resistance type, matched in intensity using RPE. Both training groups significantly improved their strength and body composition with no difference between groups.

The major limitations of this meta-analysis are that: 1) Few comparable studies were available; although trim-and-fill analysis demonstrated no evidence of publication bias for the 14 studies included in our review, some investigators have indicated that publication bias analysis should be used with caution (Hak et al., 2015). 2) The low number of total subjects would contribute to the high inter-study variability. 3) A variety of elastic materials were used in the included studies, which could have provided different resistance and loading patterns. 4) Although all of the studies included in this meta-analysis were reviewed to assure that they included a rigorous methodology, no systematic grading was used to assess the rigor of the articles. 5) All studies included the meta-analysis followed the standard procedure of EMG measurement, but different muscle groups, data acquisition systems and data analysis techniques were used in different studies; however, since all experiments used single group, within subject cross-over study design, the authors are confident that measurement and analysis techniques did not affect the final results. 6) Isoinertial exercises do not exert constant tension (isotonic) on the muscles due to differences in torque (moment arm) through the ROM; therefore, IE might not be considered a gold standard training device to compare the efficacy of elastic bands. Further studies with greater sample size are required to compare the EMG-force relationship as well as longitudinal training effects of ER with IR or isokinetic exercises machines in both rehabilitational and athletic settings.

5. Conclusions

ER provides similar prime mover, antagonist, stabilizer and assistant movers activation as IR, contradicting the traditional criticism that the elastic bands would not elicit comparable levels of muscle activation. This lack of difference might be attributed to lower than commonly speculated tension differentials through the ROM with ER. Both ER and IR exercises can be used in progressive resistance training programs with similar levels of muscle activation to be expected.

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 (Thera-band).

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