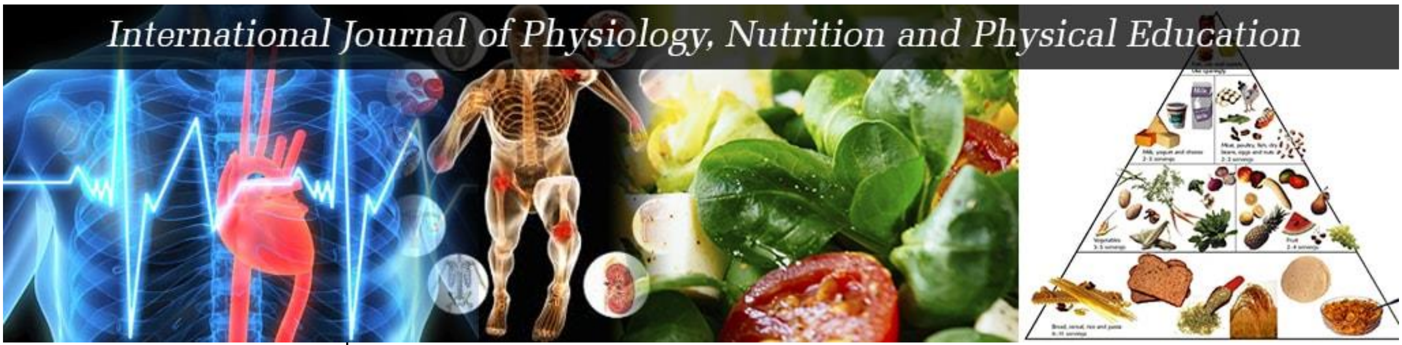

ISSN: 2456-0057
IJPNPE 2017; 2(2): 2029-2036

www.journalofsports.com
Received: 26-05-2017
Accepted: 29-06-2017

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Comparative study on multiple-joint exercises assisted by elastic resistance bands vs. conventional resistance-training equipment

Dr. Devender Prakash and Manju Dalal

Abstract
Previous studies indicate that elastic resistance bands (ERB) can be a viable option to conventional resistance-training equipment (CRE) during single-joint resistance exercises, but their efficacy has not been established for several commonly used multiple-joint resistance exercises. Thus, we compared muscular activation levels in four popular multiple-joint exercises performed with ERB (TheraBand®) vs. CRE (Olympic barbell or cable pulley machines). In a cross-over design, men and women (n = 29) performed squats, stiff-legged deadlifts, unilateral rows and lateral pulldown using both modalities. Multilevel mixed-effects linear regression analyses of main and interaction effects, and subsequent post hoc analyses were used to assess differences between the two resistance-training modalities. CRE induced higher levels of muscle activation in the prime movers during all exercises ($p < .001$ for all comparisons), compared to muscle activation levels induced by ERB. The magnitude of the differences was marginal in lateral pulldown and unilateral rows and for the erector spinae during stiff-legged deadlifts. In squats the quadriceps femoris activations were substantially lower for ERB. The differences between ERB and CRE were mostly observed during the parts of the contractions where the bands were relatively slack, whilst the differences were largely eliminated when the bands became elongated in the end ranges of the movements. We conclude that ERB can be a feasible training modality for lateral pulldowns, unilateral rows and to some extent stiff-legged deadlifts, but not for the squat exercise.

Keywords: resistance training, electromyography, cross-over studies, strength, skeletal muscle

Introduction

Resistance training induces several health benefits and is recommended for the general population (Garber *et al.*, 2011; Williams *et al.*, 2007) [9] and can be beneficial for persons with musculoskeletal disorders (Kristensen & Franklyn-miller, 2012; Van Eerd *et al.*, 2015). Resistance-training exercises can be categorized as single- or multiple-joint exercises. Multiple-joint exercises (e.g. squat) are generally considered more beneficial than single-joint exercises (e.g. knee extension) as they stimulate several muscle groups, increases overall muscular strength with fewer exercises and more closely resemble activities of daily living (Kraemer & Ratamess, 2004; Ratamess *et al.*, 2009; Schoenfeld, 2010). It is well documented that resistance training involving conventional resistance-training equipment (CRE) such as free-weights and resistance-training machines is effective in achieving strength gain (Ratamess *et al.*, 2009). Elastic resistance bands (ERB) could potentially be used as a feasible alternative for resistance training at smaller outpatient clinics and at home as they are versatile, portable, require little space and relatively cheap. Studies have found ERB to be similarly effective in activating muscles compared to CRE during single joint resistance exercises when relative loadings were matched (Aboodarda, Hamid, Muhamed, Ibrahim, & Thompson, 2013; Aboodarda, Page, & Behm, 2016; Aboodarda, Shariff, Muhamed, Ibrahim, & Yusof, 2011; Andersen *et al.*, 2010; Brandt *et al.*, 2013; Jakobsen *et al.*, 2012, 2014; Sundstrup, Jakobsen, Andersen, Jay, & Andersen, 2012) [1, 2, 3, 4, 5, 12]. However, we are only aware of two studies investigating muscle activity during multiple-joint exercises with ERB (Calatayud *et al.*, 2015; Sundstrup *et al.*, 2014) [6]. Calatayud *et al.* (2015) [6] found that performing push-ups with ERB provided similar muscular activity in the chest- and shoulder muscles as the bench press. Sundstrup *et al.* (2014) reported that performing lunges with ERB produced higher muscle activity in the gluteus maximus, hamstrings and erector spinae, but lower activation levels in the quadriceps than lunges with dumbbells and leg press in a training machine.

Despite promising indications, the viability of ERB is not established for several commonly used multiple- joint resistance exercises. In this study we evaluated the muscular activation level in four commonly used multiple-joint exercises: squats, stiff-legged deadlifts, lateral pulldown and unilateral rows – using ERB vs. CRE.

Methods

Study design

In a cross-over design, we evaluated muscular activation levels by electromyography (EMG) in multiple-joint exercises using ERB vs. CRE. EMG data were collected in two successive sessions; for lateral pulldown and unilateral row in session 1, and for squats and stiff-legged deadlifts in session 2. In addition to the primary muscles of interest, we also recorded EMG from several ancillary muscles as multiple-joint exercises activate several muscle groups. All CRE exercises were performed first (3– 5 minutes break between exercises) and then ERB exercises were conducted. The corresponding ERB exercise was performed almost an hour later than the CRE exercise. All experimental sessions were separated by at least three days, and participants were instructed to refrain from strength training three days prior to each session. Participants thirty healthy persons were recruited for the study, but one woman dropped out between the familiarization sessions and the testing sessions due to lack of time. Thus, 17 men (means ± SD) 25 ± 3 years, height 180 ± 7 cm, weight 75 ± 12 kg, body mass index (BMI) 23 ± 3 and 12 women 25 ± 2 years, height 168 ± 7 cm, weight 60 ± 7 kg, BMI 21 ± 2 completed the study. All participants provided written informed consent prior to engaging in the study.

Exercise equipment

To provide resistance with ERB, TheraBand® elastic bands with resistance ranging from light to very heavy loading (colours: yellow-gold) were used. ERBs were 2 meters, but the actual length used (grip on ERBs and distance to anchor point) was fine tuned for each subject in each exercise to find the correct resistance. When necessary to increase loading, two or more bands were combined. Bands were pre stretched and never elongated more than 300% of resting length, as recommended by the manufacturer. To provide CRE, a 20 kg Olympic barbell with free-weights, an adjustable pulley were used. Familiarization and matching of relative resistance loading two familiarization sessions were used for practicing and testing strength levels prior to the experimental testing sessions. ERB were used in the first familiarization session while CRE were used in the second session. Exercises were demonstrated and thoroughly instructed by the test leader. When a participant was able to execute an exercise correctly, a 10-repetition maximum (RM) test was performed (full dynamic movements) to match the resistance loadings used for CRE and ERB. The 10-RM loadings were determined within three to five attempts. Individual set-ups were recorded and replicated during EMG-testing. This included stance, grips, resistance loadings used in CRE, number and colours of ERBs, distance to the anchor points for ERB (pre-stretch). Postures and correct execution of technique were visually controlled.

Resistance exercises

Exercises were performed using two seconds for the concentric phase and two seconds for the eccentric phase of the movement. A metronome, set to 60 beats per minute, controlled the pace. The exercises are illustrated in the online figure. Squats. CRE was provided by an Olympic barbell resting on the participant's trapezius and shoulders.

Elastic resistance was applied by standing on the ERB(s) and pulling each end over the shoulder, holding them on the front side of the chest. The exercise was performed with a shoulder-width stance, and started in the standing position. Participants descended to a 90° knee angle, and returned to the initial position to complete one repetition. Primary muscles of interest were the superficial quadriceps muscles (vastus lateralis, vastus medialis and rectus femoris). Gluteus maximus and the erector spinae were considered important supporting muscles. Stiff-legged deadlifts. CRE was provided by holding a barbell with a shoulder-width overhand grip, and the arms hanging down close to the body. Elastic resistance was provided by anchoring the ERB(s) to a wall-bar (7 cm from the ground), pulling the ERB (s) between the legs and holding each end close to the chest. A shoulder-width stance was used. Participants bent their knees slightly and kept their back straight, pushing the hips back and lowering the upper body down as deep as possible while maintaining a neutral spine position, and return to the starting position to complete one repetition. Shoulders were pulled back during the whole movement. Primary muscles of interest were erector spinae, gluteus maximus, semitendinosus and biceps femoris. Lateral pull-downs. CRE was provided by a pulldown machine using a bar attached to a cable. The grip width corresponded to twice the bi-acromial distance. The participant was seated with the thighs under a fixed pad, pulling the bar down to the top of the chest, before returning the bar until the arms were fully extended. Elastic resistance was provided by attaching the ERB(s) around the highest bar in a wall-bar, with handles connected to each end of the ERB(s). The participant was seated on the floor with the back against the wall-bar, holding the handles with the palms pointing forward and arms fully extended, and pulling the handles down to shoulder height. The handles were then returned until the arms were fully extended. The primary muscle of interest was latissimus dorsi. Biceps brachii was considered an important supporting muscle. Unilateral rows. CRE was provided by a cable pulley apparatus. The pulley handle was adjusted to participant's elbow height, while standing. The participant held the handle with the dominant arm, took a step back to ensure that the cable was taut, and placed the non-dominant foot in front of the other and the non-dominant arm on the hip. With upright posture and starting with a straight arm, the participant pulled the handle towards the body until it was lateral to the trunk. The handle was then returned until the arm was fully extended. The participant maintained an erect posture and did not rotate the trunk. Elastic resistance was provided by attaching ERB(s) around the bar in the wall-bar closest to the participant's elbow height. One handle was connected to the ERB(s). The execution of this exercise was otherwise equal to CRE. Primary muscles of interest were latissimus dorsi and deltoideus posterior. Deltoideus medius and biceps brachii were considered important supporting muscles. In session one, erector spinae, biceps brachii, deltoideus anterior, deltoideus medius, deltoideus posterior, trapezius descendens, latissimus dorsi, obliquus externus and pectoralis major were recorded.

In session two, rectus femoris, vastus lateralis, vastus medialis, biceps femoris, semitendinosus, erector spinae, gluteus maximus and obliquus externus were recorded. Electrodes were placed in accordance with the SENIAM guidelines (http://www.seniam. org), except for those on the latissimus dorsi as no guidelines were available for this muscle. These electrodes were placed approximately one cm lateral to the inferior border of the scapula in the presumed underlying direction of the muscle fibres (Lehman, Buchan, Lundy, Myers, & Nalborczyk, 2004). The skin was gently shaved and cleaned with alcohol prior to electrode placement to minimize resistance between the electrodes (Hermens, Freriks, Disselhorst- Klug, & Rau, 2000) [11]. EMG signals were recorded through shielded wires to the EMG system (MuscleLab 4020e, Ergotest Technology AS, Langesund, Norway). In order to reduce external noise a pre-amplifier with common mode rejection ratio of 100 dB was used. The signal was filtered with a fourth-order Butterworth bandpass filter (8–600 Hz). Finally, a hardware circuit network converted the filtered EMG signals (frequency response of 0–600 kHz, averaging constant of 100 ms, and total error of ±0.5%). The root mean square signal was then sampled at 100 Hz with a 16-bit A/D converter (AD637). Normalization of EMG recordings.

At the start of each test session, two maximal voluntary isometric contractions (MVCs) were conducted for each of the muscles which were to be monitored in that session in order to induce a maximal EMG response. The MVCs for the erector spinae and all the quadriceps muscles were performed in accordance with suggested procedures (Konrad, 2005), while MVCs for the remaining muscles were standardized based on test set-ups used in our lab. Each MVC lasted five seconds and participants were instructed to gradually increase to maximum force. Standardized verbal encouragements were given. One minute of rest was given between the two MVCs, and the trial with the highest average one second EMG activity epoch was used to normalize the EMG recordings of the resistance exercises.

EMG and movement recordings The EMG recordings were collected while the participants performed three repetitions, using 10-RM loading, for each of the exercises. Prior to each CRE exercise, a warm-up set of 50% of the 10-RM loading was performed. A linear encoder (100 Hz sampling frequency, 0.075 mm resolution; ET-Enc-02, Ergotest Technology AS, Langesund, Norway) synchronized with the EMG data was used in order to detect movement and identify the different lifting phases. The string of the encoder was attached to a finger on the participants' dominant hand during all exercises. EMG and motion analysis EMG data were analyzed using Muscle Lab v8.13 (Ergotest Technology AS, Langesund, Norway). The 10–90% range of motion for each contraction phase was used in the analyses, and the time window for each of the concentric and eccentric phases was divided into two phases according to the movement amplitude – i.e. concentric phase one (C1) and two (C2), and eccentric phase one (E1) and two (E2). Three repetitions were performed for each exercise where the mean EMG activity for each of the four phases (C1, C2, E1 and E2) was calculated as follows: for the concentric phases, repetition two and three were averaged and used for analyses, while repetition one and two were averaged and used for the eccentric phases, as it was difficult to determine the exact start and stop for concentric contraction one and eccentric contraction three, respectively. The averaged EMG results were then normalized by the maximal EMG recordings from the MVCs, and are reported as a percentage of the maximal EMG activity.

Statistical analyses

Statistical analyses were conducted in STATA/IC 13.1 for windows (StataCorp LP, USA). The overall difference between resistance modalities (ERB and CRE) and interaction between resistance modalities and contraction phases for each muscle in all exercises were assessed using multilevel mixed-effects linear regression models. Normalized EMG was the dependent variable, while contraction phase and resistance modality as well as their interaction term were used as fixed effects, and participant identity as a random effect (allowing participants to start out differently). If a main effect or interaction effect was discovered, we performed post hoc analyses to determine where the differences were located. Significance level (two-tailed) was set to $p < .05$ for the main effect and interaction effect, while $p < .01$ was considered significant for the post hoc analyses considering the number of tests performed. Furthermore, all EMG variables as well as regression residuals were visually inspected for normality of distribution, using qq-plots and histograms, resulting in log-transformations of all variables. For presentation of results, the variables were back-transformed to simplify interpretation. We used a forward approach to search for confounders, meaning that we started with simple regression models without any adjustments, and then adding relevant covariates (i.e. sex, gender and age) to see if the regression coefficients changed. Covariates were considered confounders if the regression coefficient changed more than 10%. Paired t-tests were used to check for differences in perceived exertion (Borg CR10 scale) between modalities and $p < .05$ was considered statistically significant.

Results

No confounding effects of sex, BMI or age were observed. Thus, we did not adjust for baseline characteristics. Multiple-joint exercises using elastic resistance bands vs. conventional resistance-training equipment

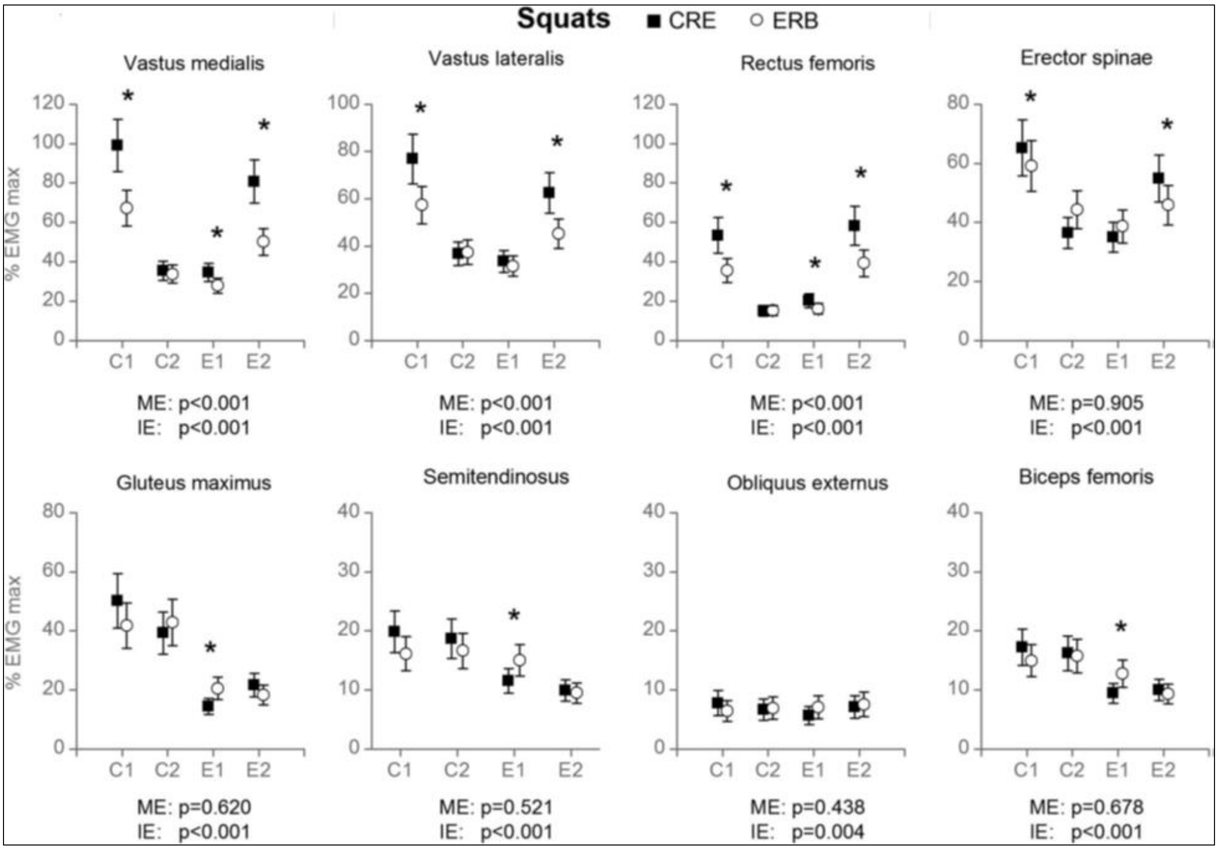

Fig 1: Normalized EMG activity (% EMG max) during squats with CRE vs. ERB. P-values for main effect (ME) of exercise modality, and interaction effects (IE) between exercise modality and contraction phases are presented. Asterisk indicate difference between exercise modalities ($p < .01$). Note different scaling of the y-axes. Values are means with 95% CI. C1 and C2: concentric phase one and two. E1 and E2: eccentric phase one and two

For the squat exercise (Figure 1), significant main effects of training modality in favour of CRE were found for vastus medialis, vastus lateralis and rectus femoris. Interaction effects between exercise modality and contraction phases were displayed in all muscles. Post hoc analysis showed significantly higher muscle activation with CRE in C1, E1 and E2 for vastus medialis and rectus femoris, C1 and E2 for vastus lateralis and erector spinae. ERB produced higher activation in E1 for gluteus maximus, semitendinosus and biceps femoris. For the stiff-legged deadlifts (Figure 2), significant main effects of modality were found in favour of the CRE exercise for all muscles except rectus femoris. Interaction effects were observed in all muscles except for the quadriceps muscles, i.e. vastus medialis, vastus lateralis and rectus femoris. Post hoc analysis showed significantly higher muscle activation with CRE in C1 and E2 for erector spinae, gluteus maximus, semitendinosus and obliquus externus, and in C1, C2 and E2 for biceps femoris. For the lateral pulldown (Figure 3), significant main effects of modality were observed in favour of CRE for latissimus dorsi, biceps brachii, deltoideus posterior and pectoralis major, while there was a main effect in favour of ERB for the obliquus externus. Interaction effects between exercise modality and contraction phase were displayed in all muscles except for latissimus dorsi and deltoideus medius. Post hoc analysis showed higher muscle activation with CRE in C1 and E2 for latissimus dorsi, biceps brachii and pectoralis major, and C1 for deltoideus posterior, deltoideus anterior and trapezius descendens. ERB produced higher activation in all phases for obliquus externus and E2 for deltoideus anterior. For the unilateral row (Figure 4), significant main effects of modality in favour of CRE were displayed for latissimus dorsi, deltoideus posterior, deltoideus medius biceps brachii, obliquus externus and trapezius descendens. Interaction effects were displayed for latissimus dorsi, deltoideus posterior, biceps brachii, erector spinae, obliquus externus and pectoralis major. Post hoc analysis showed significantly higher muscle activation with CRE in C1 and E2 for latissimus dorsi and deltoideus posterior, C1 and E1 for obliquus externus, C1 for deltoideus medius and biceps brachii, and E2 for pectoralis major. Rating of perceived exertion following the 10-RM tests of all exercises is presented in the online table.

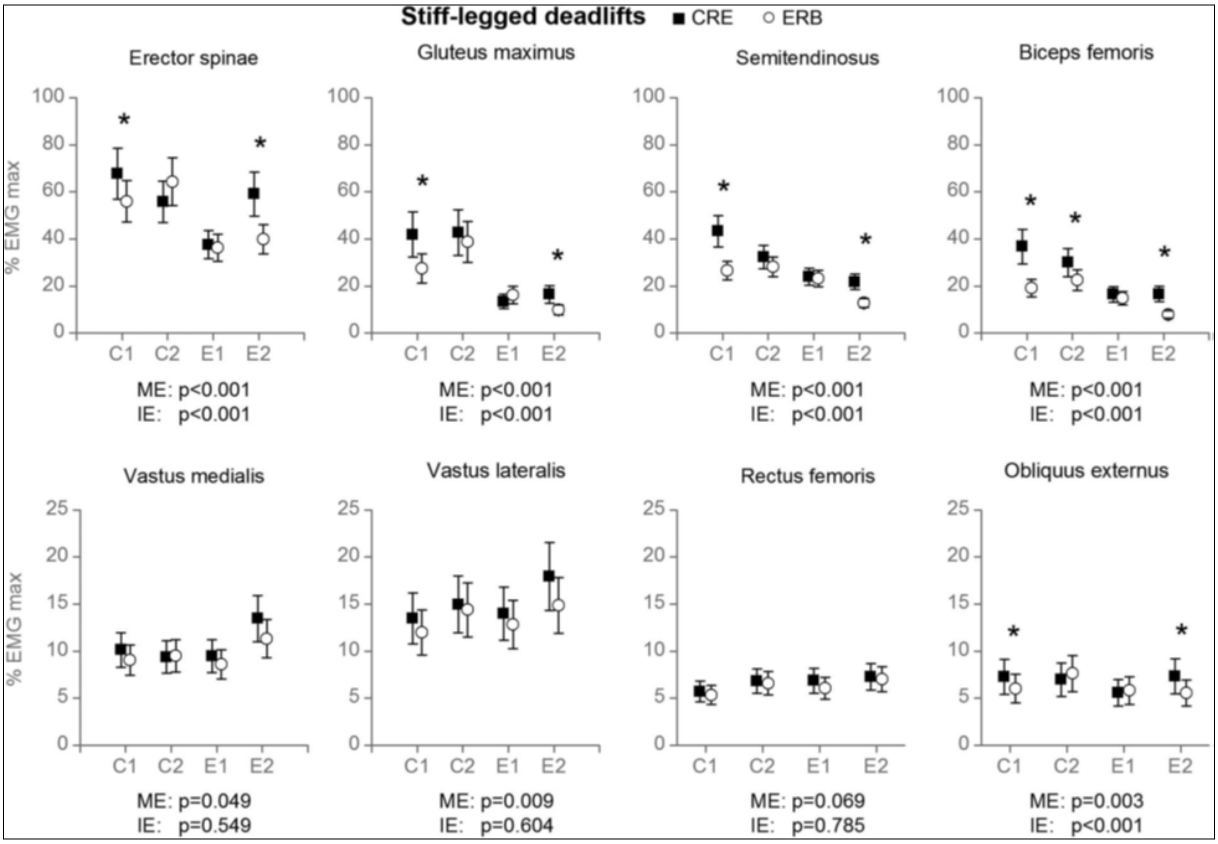

Fig 2: Normalized EMG activity ((% EMG max) during stiff-legged deadlifts with CRE vs. ERB. p-values for main effect (ME) of exercise modality, and interaction effects (IE) between exercise modality and contraction phases are presented. Asterisk indicate difference between exercise modalities (*p* < .01). Note different scaling of the y-axes. Values are means with 95% CI. C1 and C2: concentric phase one and two. E1 and E2: eccentric phase one and two

Medius and biceps Brachii, and E2 for pectoralis major. Rating of perceived exertion following the 10-RM tests of all exercises is presented in the online table. A significantly higher score was reported for stiff legged deadlifts with CRE (7.7 vs. 6.8, p = .024). A trend for higher score was observed for squats with CRE (7.5 vs. 6.9, p = .92). Mean (SD) loadings used in the CRE exercises were for men: 76.9 (14.4) kg in squats, 67.6 (23.3) kg in stiff-legged deadlifts, 50.5 (9.5) kg in lateral pulldown, and 31.8 (8.0) kg in unilateral rows, and for women: 50.6 (11.5) kg in squats, 51.5 (13.5) in stiff-legged deadlifts, 33.8 (8.3) kg in lateral pulldown, and 23.8 (5.1) kg in unilateral rows.

Discussion

This is the first study comparing ERB with CRE for several commonly used multiple-joint exercises. We found that ERB overall provided marginally lower muscle activation levels relative to CRE for the prime movers in lateral pulldown and unilateral rows, somewhat lower for stiff-legged deadlifts and considerably lower for squats. The differences between ERB and CRE were mostly observed during the parts of the contractions where the bands were relatively slack, whilst the differences were largely eliminated when the bands became elongated at the end range of the movements. The findings for lateral pulldown and unilateral rows are partially consistent with findings by Calatayud *et al.* (2015) [6] who reported that push-ups performed with ERB were equally effective to bench press in activating the prime movers (pectoralis major and deltoideus anterior). However, as pushups is a relatively heavy bodyweight exercise, the ERB component would account for a smaller fraction of the total resistance than in our study which could explain the difference between Calatayd *et al.* and our study. Nevertheless, as the overall magnitude of the differences was quite small for all prime movers in both lateral pulldown (11–15%) and unilateral row (11–13%), ERB can likely be a viable training modality for these exercises. Multiple-joint exercises using elastic resistance bands vs. conventional resistance-training equipment.

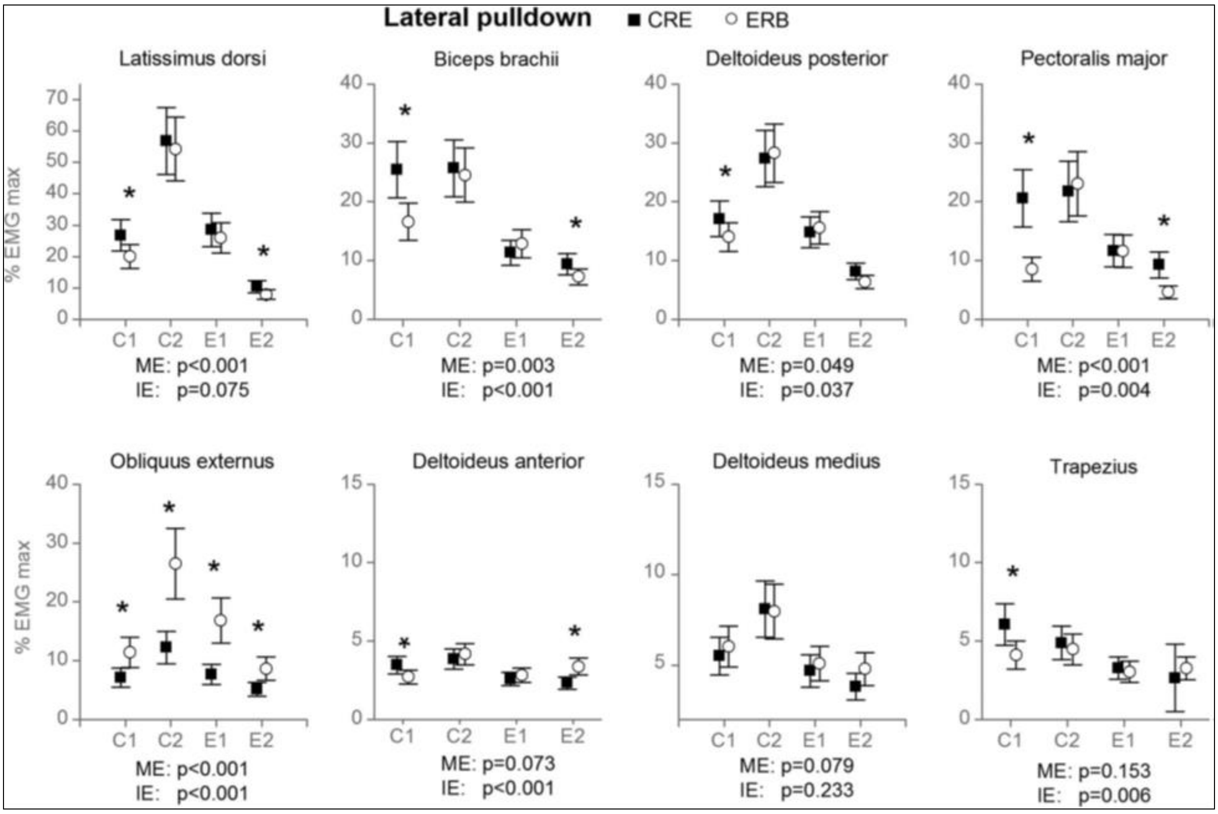

Fig 3: Normalized EMG activity (% EMG max) during lateral pulldown with CRE vs. ERB. P-values for main effect (ME) of exercise modality, and interaction effects (IE) between exercise modality and contraction phases are presented. Asterisk indicate difference between exercise modalities ($p < .01$). Note different scaling of the y-axes. Values are means with 95% CI. C1 and C2: concentric phase one and two. E1 and E2: eccentric phase one and two

Our findings of inferior activation of the primary movers during stiff-legged deadlifts and particularly squats with ERB are consistent with the findings by Sundstrup *et al.* (2014) who reported lower activation of the prime mover (quadriceps muscles) with ERB- vs. CRE lunges and unilateral leg press. Still, Sundstrup *et al.* concluded that ERB was a viable option, as ERB induced higher or similar activation of other important muscles (gluteus, erector spinae and hamstring muscles). Partly in line with this, ERB and CRE induced similar activation levels for important supporting muscles during squats in our study (i.e. gluteus maximus and erector spinae). Nevertheless, the substantially lower quadriceps activation with ERB suggests that CRE should be preferred for squats. Additionally, CRE should be the favoured training modality for stiff-legged deadlifts, but depending on the goal of training, ERB could be utilized as a viable option in this exercise since the magnitude of the difference in erector spinae activation was relatively small (11%). Differences in EMG between ERB and CRE in our study were generally observed when ERBs were least elongated (C1 and E2) while activation levels were quite similar in the end ranges. This is probably a direct consequence of the difference in tensile force throughout the range of motion with ERB, whereas CRE provided constant external resistance. Other studies investigating ERB multiple-joint exercises did not investigate activation levels related to elongation of the ERB (Calatayud *et al.*, 2015; Sundstrup *et al.*, 2014) [6]. However, our finding corresponds with studies on single-joint exercises (Aboodarda *et al.*, 2013; Jakobsen *et al.*, 2012, 2014) [1, 12].

From a practical perspective, it could be useful to perform ERB exercises with a considerable prestretch to reduce the difference in external loading throughout the range of motion, when this is feasible (e.g. unilateral row). However, there is limited opportunity for manipulating the amount of pre-stretch in exercises where the height of the person is the limiting factor (e.g. squat). Contrary to the upper-body exercises, it appeared challenging to reach high activation levels for some important muscles with ERB in stiff-legged deadlifts and particularly squats. For stiff-legged deadlifts, in particular, there were differences in the execution of CRE and the comparative ERB exercise.

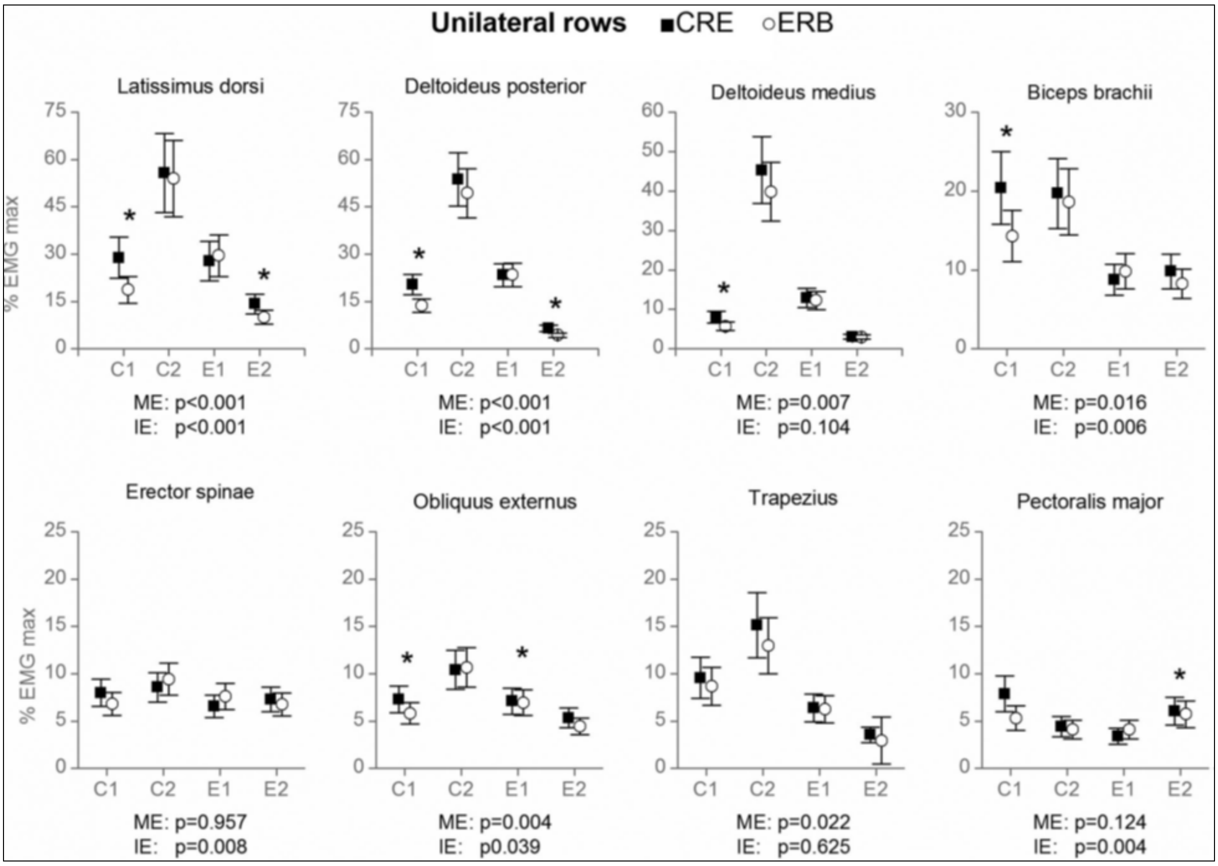

Fig 4: Normalized EMG activity (% EMG max) during unilateral rows with CRE vs. ERB. P-values for main effect (ME) of exercise modality, and interaction effects (IE) between exercise modality and contraction phases are presented. Asterisk indicate difference between exercise modalities ($p < .01$). Note different scaling of the y-axes. Values are means with 95% CI. C1 and C2: concentric phase one and two. E1 and E2: eccentric phase one and two

While the weighted barbell provided a gravitational downward pull, the ERB was attached behind the participants, altering the biomechanical requirements of the exercise, which likely affected EMG activity. Additionally, both squats and stiff-legged deadlifts are versions of powerlifting exercises in which very heavy weights can be lifted (Garhammer, 1993) [10] and it could be that CRE is better for handling such heavy loads, perhaps due to the considerable difference in external loading in the phases where the bands are slack. Still, one study reported similar improvements in isometric squat- and back extension strength after eight weeks of resistance training which included the exercises squats and stiff-legged deadlifts with ERB vs. CRE (Colado *et al.*, 2010) [7].

However, as the programme included several other exercises it is difficult to ascribe the findings to these two exercises. The ERB training in that study was performed with TheraBand® Exercise stations – resulting in less diversity in exercise movements across the modalities. This was not done in this study, as it would have been contradictory to the overall aim of the study – to assess ERB as an easy to use and portable resistance-training modality.

Nevertheless, more similar exercise set-ups between modalities might have reduced the differences in muscular activation. Ratings of perceived exertion using the Borg CR10 scale have been found to give an adequate reflection of the muscular activation of ERB and CRE (Andersen *et al.*, 2010; Brandt *et al.*, 2013) [4, 5]. Similar perceived exertion in the use of ERB and CRE was reported for lateral pulldown and unilateral rows. The finding of stiff-legged deadlifts and squats being more exhausting for CRE (only a trend for squats) is in line with higher activation of the prime movers for these exercises. Nevertheless, it could be that the lower perceived exertion with ERB could make these exercises more tolerable for patients and the general population.

Limitations

Some limitations should be acknowledged. Only young, healthy individuals were recruited. The results can therefore not necessarily be generalized to other populations. Furthermore, it is challenging to determine the exact 10-RM with ERB, which creates some uncertainty about the matching of resistance loadings. To overcome this issue in practical settings, we recommend prescribing repetitions in wide interval ranges (e.g. 6–12, 10–15). For logistical reasons, the order of testing was not randomized (CRE performed before ERB); however, as participants only performed three repetitions with 10-RM loadings and the time between the two equivalent CRE and ERB exercises was close to an hour, we consider it unlikely that the activation levels were substantially affected. Finally, surface EMG only provides an estimate of neural activation, and there is always a possibility for cross-talk from nearby muscles despite precautions during electrode placements (Farina, 2006). Importantly, EMG data were collected in the same session for all relevant comparisons – without removing and replacing electrodes, with a standardized movement velocity.

Conclusion

In conclusion, ERB generally produced similar muscular activation levels as CRE in the end ranges where the bands were stretched, while somewhat lower activation levels were observed for ERB when the bands were relatively slack. As a training modality, ERB seems to be a viable option to CRE for the exercises' lateral pull-downs and unilateral rows, but not so much for stiff-legged deadlifts and particularly squats. Nevertheless, ERB provided largely similar activation levels of the erector spinae in stiff-legged deadlifts and for gluteus maximus and erector spinae in squats, which could make the exercises viable for patients (e.g. low back pain) who wish to strengthen their lower back and hip extensors.

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