Assessment of muscle activity using elastic resistance in strength exercise

Ronny Bergquist

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Department of Neuroscience, NTNU

Trondheim, Norway

Abstract

Strength exercise is associated with many positive health effects. However, many people do not have the opportunity to use conventional strength exercise equipment. Studies have shown that elastic resistance can induce similar levels of muscle activity as when exercising with isotonic resistance. The exercises previously investigated is however limited, and few studies have investigated whether muscle activation differ in the different phases of a contraction. In this study, face pulls, rowing, lateral pull-down, flies, reversed flies, and squat was performed by 29 subjects to assess the muscle activity level with elastic vs. isotonic resistance. Muscle activity was measured for three muscles in each exercise, using surface electromyography (EMG). The root-mean-square EMG signal was normalized to the maximal EMG (i.e., EMG_{max}) elicited during a maximal voluntary contraction. A linear encoder was also used so that any differences in muscle activity between the specific phases of a contraction could be assessed. The load used during the two modalities was matched using a 10 repetition maximum protocol. A significant main effect of exercise modality on muscle activity was found in 12 of the 18 combinations (three muscles in six exercises). Among these, eight combinations showed a significantly higher muscle activity using isotonic resistance, and four with elastic resistance. In the remaining six combinations, no significant differences were found. Significant interaction effects were found in 16 of the 18 combinations, i.e., muscle activity was affected by contraction phase. Overall, the absolute difference in muscle activity between elastic and isotonic resistance was small and not likely to have any physiological relevance. In conclusion elastic bands seem to be a feasible alternative to conventional strength exercise equipment for everyone interested in the benefits associated with strength exercise.

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Introduction

Physical exercise performed on a regular basis is associated with many physical and mental health benefits, and is commonly divided into exercise for endurance, strength and flexibility. Traditionally, endurance exercise has been considered superior in improving health compared to the other forms of exercise. However, studies indicating positive health effects of regular strength exercise have grown in numbers the past years. Higher levels of strength have been associated with a significantly better cardiometabolic risk factor profiles (Jurca et al., 2005), lower all-cause mortality risk (Ruiz et al., 2008), and fewer events of cardiovascular death (Gale et al., 2007). Resistance exercise is positively associated with a higher level of bone mineral density in both young people and adults (Guadalupe-Grau et al., 2009), while low strength levels have been identified as a risk factor for developing osteoarthritis (Slemenda et al., 1998). Regular strength exercise can also improve several biomarkers associated with metabolic syndrome, blood glucose levels (Castaneda et al., 2002), insulin sensitivity (Brooks et al., 2007), and blood pressure in persons with prehypertension (Collier et al., 2009).

Strength exercise has shown to be especially effective in reducing pain in several musculoskeletal conditions, including neck pain (Andersen et al., 2008; Waling et al., 2000), chronic nonspecific low-back pain (Kell and Asmundson 2009) and knee osteoarthritis (Ettinger et al., 1997; Gur et al., 2002; Huang et al., 2003). In patients with knee osteoarthritis, it has been proposed that degree of pain and physical disability is associated with weakness in the knee extensors (Gur et al., 2002). Accordingly, progressive strength exercise of the knee extensors should be included as a component in the treatment regime (Lange et al., 2008). For trapezius myalgia, a condition characterized by pain in the descending part of trapezius, Andersen et al., (2008) found that resistance exercise with high intensity, i.e., using a relatively heavy load, decreased pain levels to a greater extent than aerobic exercise.

Limitations associated with the equipment used in conventional resistance exercise might restrain therapists and patients from using it. Barbells, dumbbells, weight-plates and machines take up a lot of space, it is heavy and stationary, and relatively expensive. Moreover, many people might not have the interest or opportunity to frequently exercise at a training center. An alternative way of exercising with resistance is by using elastic bands and tubes, or elastic resistance. This exercise modality gives the user the opportunity to perform many of the same exercises as with conventional equipment, with the main difference being the type of resistance. When using barbells, dumbbells or machines, the resistance does not change during the range of motion, i.e., it is isotonic (Patterson et al., 2001). With elastic resistance the resistance increases with increased elongation of the band.

Elastic bands come with different loads, usually indicated by different colors, making it possible to regulate the exercise intensity. This is of particular interest, considering the important role the intensity of exercise appears to have on physiological adaptations. On muscle cellular level, the most pronounced adaptations in novices is seen in periodized dynamic resistance exercise when using a load that can be performed for 8-12 repetitions maximum (RM), when both concentric and eccentric phases are involved (Kraemer et al., 2002). Thus, adaptations such as increased strength and muscle mass are gained at a higher rate when exercising at a higher intensity. It therefore seems clear that if one wishes to use elastic resistance to reap the potential benefits that come along with strength exercise the intensity needs to be sufficiently high. Because an approximate linear relation exists between isometric muscle force and EMG activity (Milner-Brown and Stein 1975; Thorstensson et al., 1976), EMG can be used to estimate exercise intensity. EMG activity reflects the summation of action potentials travelling along the muscle membrane. The root-mean-square (RMS) EMG signal is often quantified by normalizing the signal to the maximum EMG amplitude elicited during a maximum voluntary isometric contraction. The normalized EMG signal then reflects a percentage of maximum activation (Andersen et al., 2006).

Several studies have used EMG to compare muscle activation during strength exercise using elastic and isotonic resistance. Overall, the findings indicate that when the load is matched, similar levels of muscle activation can be achieved when performing lateral raise, wrist extension and shoulder external rotation (Andersen et al., 2010), hip abduction/adduction (Brandt et al., 2013), knee extension (Jakobsen et al., 2012), knee flexion (Jakobsen et al., 2014), abdominal crunch (Sundstrup et al., 2012), lunges (Sundstrup et al., 2014), and push-ups (Calatayud et al., 2015). Only two of the studies have investigated if muscle activity patterns during exercise with elastic and isotonic resistance are different across different phases of a contraction (Jakobsen et al., 2012; Jakobsen et al., 2014). Jakobsen and collegues (2012; 2014) found that during knee flexion and extension, the angle at which muscle activity peaked was different for isotonic and elastic resistance. They found a tendency for peak EMG to occur towards angles where the elastic band was more stretched. The results from these studies encourage investigating if similar muscle activity patterns between elastic and isotonic resistance exist in other exercises as well.

The main objective of this study was therefore to compare muscle activation levels with surface EMG during face pulls, rowing, lateral pull-down, flies, reversed flies and squat with elastic and isotonic resistance. A second objective was to investigate if EMG levels across the various phases of a contraction were different between the two modalities. It was hypothesized that overall EMG levels would be comparable, but that late in the concentric phase EMG levels would be higher when using elastic resistance compared to isotonic resistance, due to the elongation of the elastic bands.

Methods

Subjects

Twenty-nine subjects were recruited. Characteristics of the subjects in this study are presented in table 1. The study conformed to the Declaration of Helsinki and the study protocol was approved by the Regional Ethics Committee. All subjects gave written consent before participating in the study.

Table 1. Characteristics of the subjects included in this study. Values are mean (SD) if not otherwise stated.

Male/female	(17/12)
Age (years)	25 (2.5)
Height (cm)	175 (8.6)
Weight (kg)	69.2 (12.4)
BMI	22.5 (3.0)

BMI, body mass index.

Familiarization

All subjects performed a 10 RM test for all exercises, using elastic resistance on day 1 and isotonic resistance on day 2. Of the 29 subjects, 19 used isotonic resistance on the first day of testing, while 10 used elastic resistance. The subjects were instructed to abstain from strength exercise for at least three consecutive days before test days to minimize the effect of fatigue. The order of exercises within each exercise modality was standardized as follows: squat, lateral pull-down, face pulls, rowing, flies, and reversed flies. With this order, the largest muscle groups were tested first.

Prior to the 10 RM test, a demonstration of correct execution was given, and the subjects was allowed to practice the techniques. When the subject could perform the exercise with proper technique, the load was gradually increased for at least two warm-up sets. Larger increments in load were then made, and the subjects were encouraged to stop during a set if the load felt easy enough to perform more than 10 repetitions. With elastic resistance, the load was manipulated by increasing the number of bands and/or by changing the distance between the subject and the anchor point. Combination of bands and distance was recorded for all subjects so that the load could be replicated. However, as per recommendations from the manufacturer, the elastic bands were never stretched to >300% of resting length. With isotonic resistance, the weight was changed into a lighter or heavier one. When finding a load that the subject could perform 10 repetitions with but not more, and while maintaining proper technique, the load was used in later EMG recording.

Borg CR10

Before testing, the subjects were explained how to use the Borg CR10 scale (Borg 1998). Immediately after performing what was assumed to be a 10 RM attempt, the subject was asked to rate the perceived loading. It has previously been demonstrated a moderate to strong relation between ratings on Borg CR10, actual loading, and muscle activity levels using elastic and isotonic resistance (Andersen et al., 2010).

Exercise description

All exercises are illustrated in figure 1 and 2.

Face pulls

Isotonic resistance was provided using a cable pulley with a rope attached to it. The pulley was adjusted to shoulder height. Standing with one foot in front of the other and with an erect posture, leaning slightly backwards, the subject pulled the rope in a straight line towards the face while pointing the elbows out to the sides. Upper arms were kept above perpendicular to the trunk during the whole range of motion. The rope was then returned until arms were fully extended. Elastic bands were attached to a wall-bar in shoulder height to provide elastic resistance. Execution of this exercise was otherwise equal to the execution with isotonic resistance.

Lateral pull-down

Isotonic resistance was provided using a classic pull-down machine using a cable bar. Grip width corresponded to twice the biacromial distance. The subject was seated with thighs under a support pad, pulling the bar down to top of the chest, before returning the bar until shoulders were fully extended. Elastic resistance was provided by attaching the elastic band(s) around the highest bar in a wall bar, with handles connected to each end of the band(s). The subject was seated on the floor with the back against the wall-bar, holding the handles with the palms pointed in a forward direction and arms fully extended. The band(s) were then pulled down to shoulder height, before returning to starting position. When necessary, a rolled up sleeping pad was pressed down on the subject's thighs to prevent the subjects from pulling themselves up.

Figure 1. Illustration of face pulls (a), lateral pull-down (b), and rowing (c), using isotonic (1) and elastic (2) resistance.

Rowing

Isotonic resistance was provided using a pulley apparatus. The cable was adjusted vertically to correspond with the subjects elbow height, and then connected to a handle. The subject held the handle with the dominant arm and placed the non-dominant foot in front of the other for support. The non-dominant arm on was placed on the hip. With erect posture and a straight arm, the subject pulled the handle towards the body and stopped when the handle was lateral to the trunk. The subject was instructed not to compensate by rotating the trunk. The handle was then returned to starting position. Elastic resistance was provided by attaching elastic band(s) to a wall-bar in elbow height. One handle was connected to the ends of the band(s). Execution of this exercise was otherwise equal to the execution with isotonic resistance.

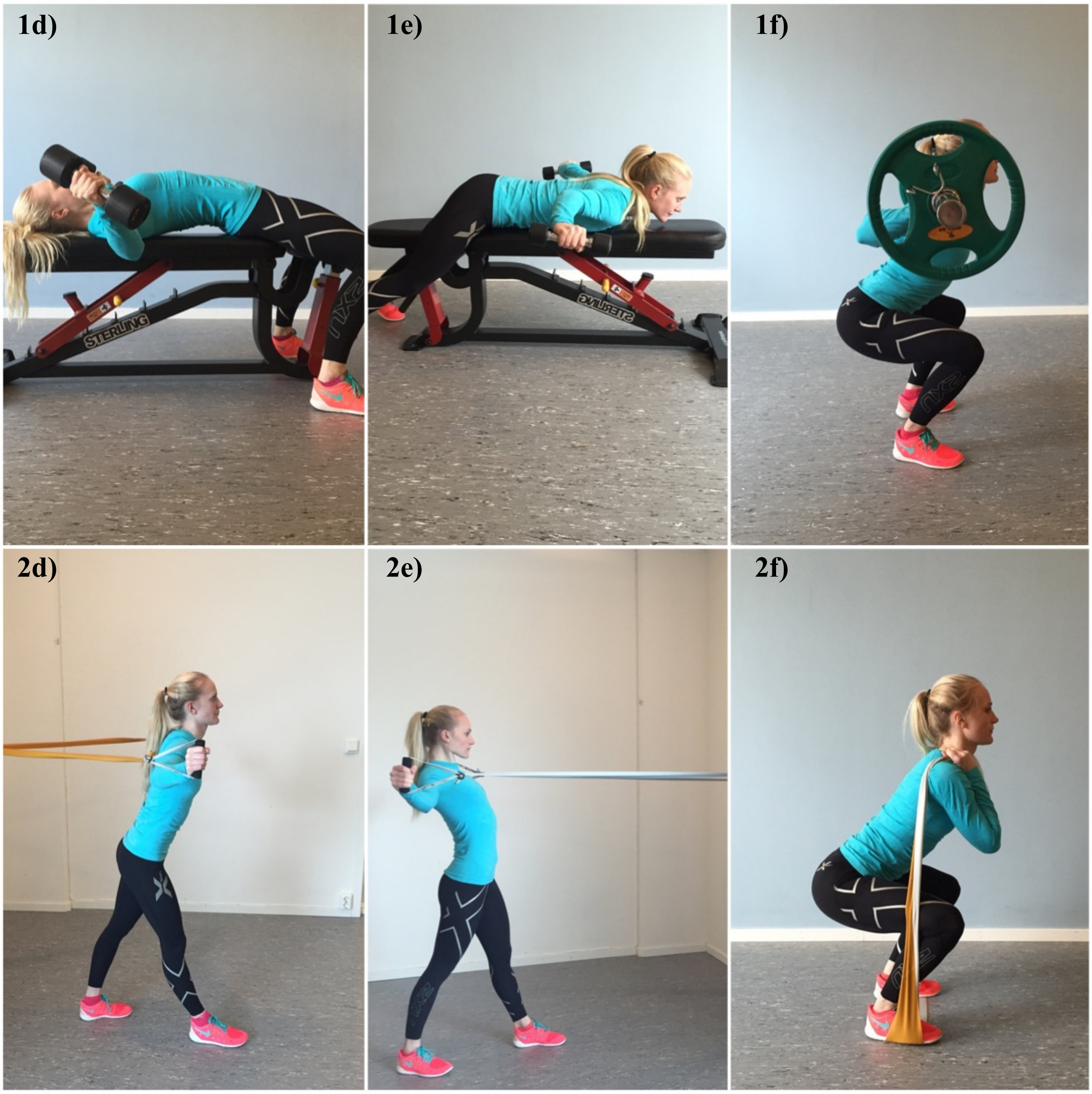


Figure 2. Illustration of flies (d), reversed flies (e), and squat (f), using isotonic (1) and elastic (2) resistance.

Flies

Isotonic resistance was provided using dumbbells. The subject lied on a bench in a supine position, holding one dumbbell in each hand with arms erect in a straight vertical line towards the roof. The subjects were instructed to maintain a slight bend in the elbow throughout the movement. When starting, the dumbbells were lowered to the sides and stopped when the humerus was parallel to the floor. The dumbbells were then returned to the starting position. Elastic resistance was provided by attaching elastic band(s) to a wall-bar in shoulder height.

Handles were connected to each end of the band, and the subject started the exercise facing away from the wall-bar, in a position where the arms were kept extended in a forward straight line parallel to the floor, while leaning the upper body slightly forward. The non-dominant foot was placed in front of the other for support. With a slight bend in the elbows, the arms were then moved out to the sides and behind, until the upper arms formed a straight line through the torso. The movement was completed by pressing the handles toward each other.

Reversed flies

Isotonic resistance was provided using dumbbells. The subject lied on the bench in a prone position, with one dumbbell in each hand, keeping the arms erect in a straight vertical line towards the floor. The subjects were instructed to maintain a slight bend in the elbow throughout the movement. The movement started by elevating the dumbbells out to the sides, returning them when the upper arms were elevated to a position parallel to the floor. Elastic resistance was provided by attaching elastic band(s) to a wall-bar in shoulder height. Handles were connected to each end of the band, and the subject started the exercise facing the wall-bar in a position where the arms were kept extended in a forward straight line, parallel to the floor. The handles were then pulled out to the sides until the upper arms formed a straight line through the torso. The handles were then returned to starting position.

Squat

Isotonic resistance was provided by a barbell. The subject started in a position with self - selected grip width and shoulder-width distance between heels. The movement was initiated by bending the hips and knees and descending until the knee angle was approximately 90°. Elastic resistance was provided with elastic band(s). The elastic band was aligned on the floor, and the subjects stepped onto the middle with the same width as with barbell squat. Further, the subject picked up both ends and dragged them over the shoulders from behind, ending up with each end in a tight grip above the chest. Finally, the subject raised into a standing position. Execution of this exercise was otherwise equal to the execution with isotonic resistance.

Exercise equipment

For the squat, a standard olympic barbell (20 kg) was used. The one-arm row and face pulls exercises were performed with an adjustable pulley (IT9125, Impulse Fitness, Newbridge, Midlothian, Scotland). For flies and reversed flies, dumbbells ranging from 1-25kg were used, with intervals of 1 kg up to 10 kg, and 2.5 kg from 10-22.5 kg. For the elastic resistance exercises, TheraBand® elastic bands and TheraBand® exercise handles were used (Hygenic Corporation, Akron, OH, USA). Resistances available were yellow, red, green, blue, black, silver and gold, which, at 200% elongation corresponds to 2, 2.5, 3, 3.9, 4.6, 6.9 and 9.5 kg, respectively. A metronome application (Metronome, Sanity software, USA) was used on an iPhone (Apple Inc, Cupertino, CA, USA).

Maximal voluntary contraction

Before performing EMG tests in the exercises with isotonic and elastic exercises, maximal voluntary contractions were recorded. EMG and maximal voluntary contraction testing was performed for upper and lower extremities on day 3 and 4, respectively. Guidelines regarding rest between day 3 and 4 was not given. On day 3, maximal voluntary contraction testing was performed on the following muscles: biceps brachii, deltoideus anterior, deltoideus medius, deltoideus posterior, trapezius descendens, latissimus dorsi, and pectoralis major. On day 4, maximal voluntary contractions were performed on vastus lateralis, vastus medialis, and gluteus maximus. The procedure for maximal voluntary contraction testing was standardized, and two tests were performed on each muscle. Subjects were instructed to gradually increase force to a maximal level within 2-3 sec and holding it until told to stop. Each test lasted in total 5 sec. Strong verbal motivation was standardized and given to all subjects. A second maximal voluntary contraction was performed 1 min after ending the first one, and the test with the highest recorded EMG signal for each muscle was used for normalization of the EMG signals.

Test procedure

The subjects started by performing one set at 50% of 10 RM load in each of the isotonic resistance exercises as a warm-up and to ensure that the subject remembered how to properly perform the exercise. A linear encoder was attached to a key ring around the subjects' finger. The metronome set on 60 bps was turned on. The subject then performed three repetitions with the 10 RM load, using approximately 2 sec on the concentric and eccentric phase, respectively. All tests were performed with isotonic resistance before elastic resistance. On day 3, EMG was recorded during upper body exercises in the following order: lateral pull-down, face pulls, one-arm row, flies, and reversed flies. Squat was tested on day 4.

EMG sampling

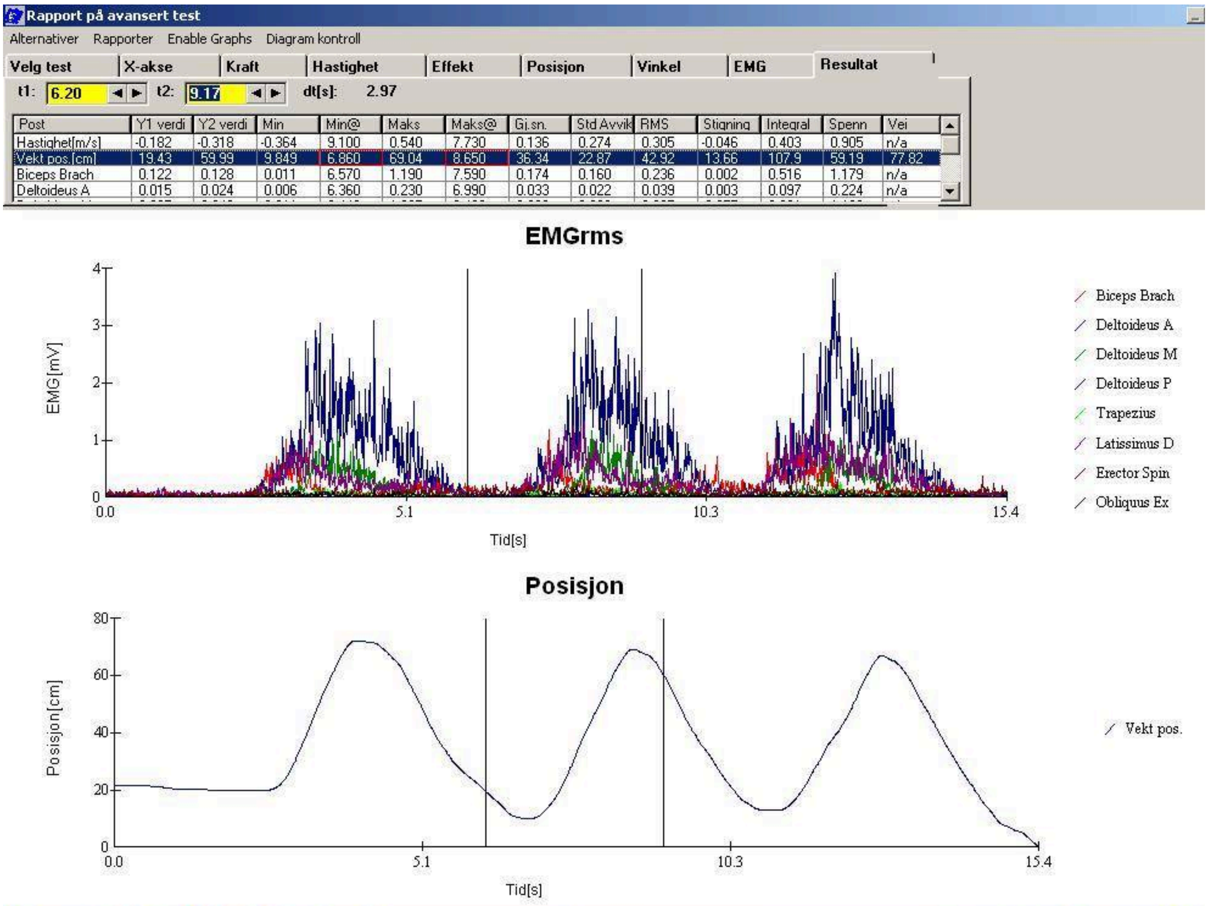
EMG signals were sampled using self-adhesive, gel-coated electrodes with a centre-to-centre distance of 20 mm (Blue Sensor, M-00-S, Ambu A/S, Ballerup, Denmark). Before electrode placement, the skin was abraded and washed with alcohol. Electrodes were placed on the subject's dominant side, and placement followed SENIAM guidelines (http://www.seniam.org) when this was available. For pectoralis major, the electrodes were placed ~4 cm medial to the axillary fold (Schick et al., 2010), and for the latissimus dorsi, electrodes was placed ~1 cm lateral to the inferior border of scapula (Lehman et al., 2004). The EMG signal was recorded through shielded wires to the EMG system (MuscleLab 4020e, Ergotest Technology AS, Langesund, Norway). A pre-amplifier near the recording site was used to minimize external noise, with a common mode rejection ratio of 100 dB. The signal was filtered using a fourth-order Butterworth filter with a bandwidth of 8-600 Hz. A hardware circuit network was used to convert the filtered EMG signals, with a frequency response of 0-600 kHz, averaging constant of 100 ms, and total error of ±0,5 %. The RMS signal was then sampled at 100 Hz with a 16-bit A/D converter (AD637).

Motion recording

To measure EMG in the different phases of contraction, a linear encoder was used and synchronized with the EMG signals (sampling frequency of 100 Hz, resolution of 0.075 mm; ET-Enc-02, Ergotest Technology AS, Langesund, Norway). The linear encoder was placed on the floor during isotonic and elastic resistance squats, lateral pull-down, and during isotonic resistance flies and reversed flies. During isotonic and elastic resistance one-arm row and face pulls, as well as elastic resistance flies and reversed flies, the linear encoder was attached on the wall close to the attachment point of the elastic band/cable. The encoder string was attached around the subjects' finger.

EMG and motion analysis

Commercial software was used for analyzing the RMS EMG and position signals (MuscleLab V8.13, Ergotest Technology AS, Langesund, Norway). The start and end of each contraction was identified from the position data by placing two cursors on each side of a concentric or eccentric contraction, as seen in Figure 3. The time at which the lowest and highest point of movement recorded with the encoder is expressed in the red squares. The cursors were then placed 10% to the right and left, respectively, of these time points. Time from the first to the second cursor reflects 10-90% of the concentric or eccentric phase of a contraction. This time window was then split in two – constituting the first and second half of the concentric (denoted as con1 and con2) and eccentric (denoted as ecc1 and ecc2) phase of a contraction. This was done in order to avoid the artifacts from the elastic band touching the electrodes in the bottom and top when performing squat. Mean RMS EMG values in these time windows was calculated and averaged from two contractions in each series of three. For the concentric phase the last two of the three performed repetitions were used, while for the eccentric phase the first two contractions were used. This was done because start/stop point was difficult to identify in the concentric and eccentric phase of the first and last repetition, respectively. The mean RMS EMG obtained during con1, ecc1, con2, and ecc2 was then normalized to the maximal EMG signal, i.e., $\%EMG_{max}$, obtained from the maximal voluntary contraction tests for all muscles.



t1: 6.20 t2: 9.17 dt[s]: 2.97

Post	Y1 verdi	Y2 verdi	Min	Min@	Maks	Maks@	Gj.sn.	Std Avvik	RMS	Stigning	Integral	Spenn	Vei
Hastighet[m/s]	-0.182	-0.318	-0.364	9.100	0.540	7.730	0.136	0.274	0.305	-0.046	0.403	0.905	n/a
Vekt pos.[cm]	19.43	59.99	9.849	6.860	69.04	8.650	36.34	22.87	42.92	13.66	107.9	59.19	77.82
Biceps Brach	0.122	0.128	0.011	6.570	1.190	7.590	0.174	0.160	0.236	0.002	0.516	1.179	n/a
Deltoideus A	0.015	0.024	0.006	6.360	0.230	6.990	0.033	0.022	0.039	0.003	0.097	0.224	n/a

Figure 3. Shows a screenshot of rowing in the EMG analysis software.

Statistical analysis

A two-way (2x4) repeated measures analysis of variance (ANOVA) (SPSS Statistics 21, Chicago, USA) was used to assess the effect of exercise modality (elastic vs. isotonic resistance) and interaction with contraction phase (con1, con2, ecc1, and ecc2) on muscle activity. The dependent variable was $\%EMG_{max}$. For the rating of perceived loading on Borg CR10 scale, a paired samples t-test was used. A p-value of 0.05 was considered as significant. The data was checked for normality with a Shapiro-Wilks test. A log-transformation was performed on variables that were not normally distributed.

Results

Table 1 shows the mean rating of subjectively perceived loading of the 10 RM test in all exercises with elastic and isotonic resistance. A significant difference was found for reversed flies with elastic resistance being rated as heavier than isotonic resistance (p=0.04).

Table 1. Perceived loading rated on the Borg CR10 scale after 10 RM tests with elastic and isotonic resistance. Values are mean (SD).

Exercises	Elastic	Isotonic	p-value
Face pulls	7.3 (1.6)	7.5 (1.4)	0.514
Lateral pull-down	7.9 (1.4)	8.0 (1.3)	0.771
Rowing	7.5 (1.5)	7.6 (1.6)	0.793
Flies	8.2 (1.2)	7.8 (1.3)	0.073
Reversed flies	7.9 (1.4)	7.1 (1.9)	0.040
Squat	6.9 (1.8)	7.5 (1.4)	0.093

* Paired samples t-test

Figure 4 shows muscle activity values when using elastic vs. isotonic resistance, for three muscles in face pulls (A-C), lateral pull-down (D-F), and rowing (G-I). Figure 5 shows similar data for flies (A-C), reversed flies (D-F), and squat (G-I). A significant main effect of exercise modality on muscle activity was found in 12 of the 18 combinations (three muscles in six exercises). When using elastic resistance, muscle activity was significantly higher for deltoideus anterior and biceps when performing flies, and for trapezius and deltoideus medius when performing reversed flies. No significant differences in muscle activity were found for trapezius and biceps in face pulls; biceps and deltoideus posterior in pull-down; biceps in rowing; and gluteus maximus in squat. When using isotonic resistance, muscle activity was significantly higher for deltoideus posterior in face pulls; latissimus dorsi in lateral pull-down; latissimus dorsi and deltoideus posterior in rowing; pectoralis major in flies; deltoideus posterior in reversed flies; vastus lateralis and vastus medialis in squat.

Figure 4 and 5 shows that in all combinations with significant main effects, significant interaction effects of contraction phase were also present. Additionally, significant interaction effects were found for biceps and deltoideus posterior in lateral pulldown, for biceps in rowing, and for gluteus maximus in squat. Significant interaction effects are only expressed within the concentric and eccentric phases, i.e., between con1 and con2, and ecc1 and ecc2, respectively.

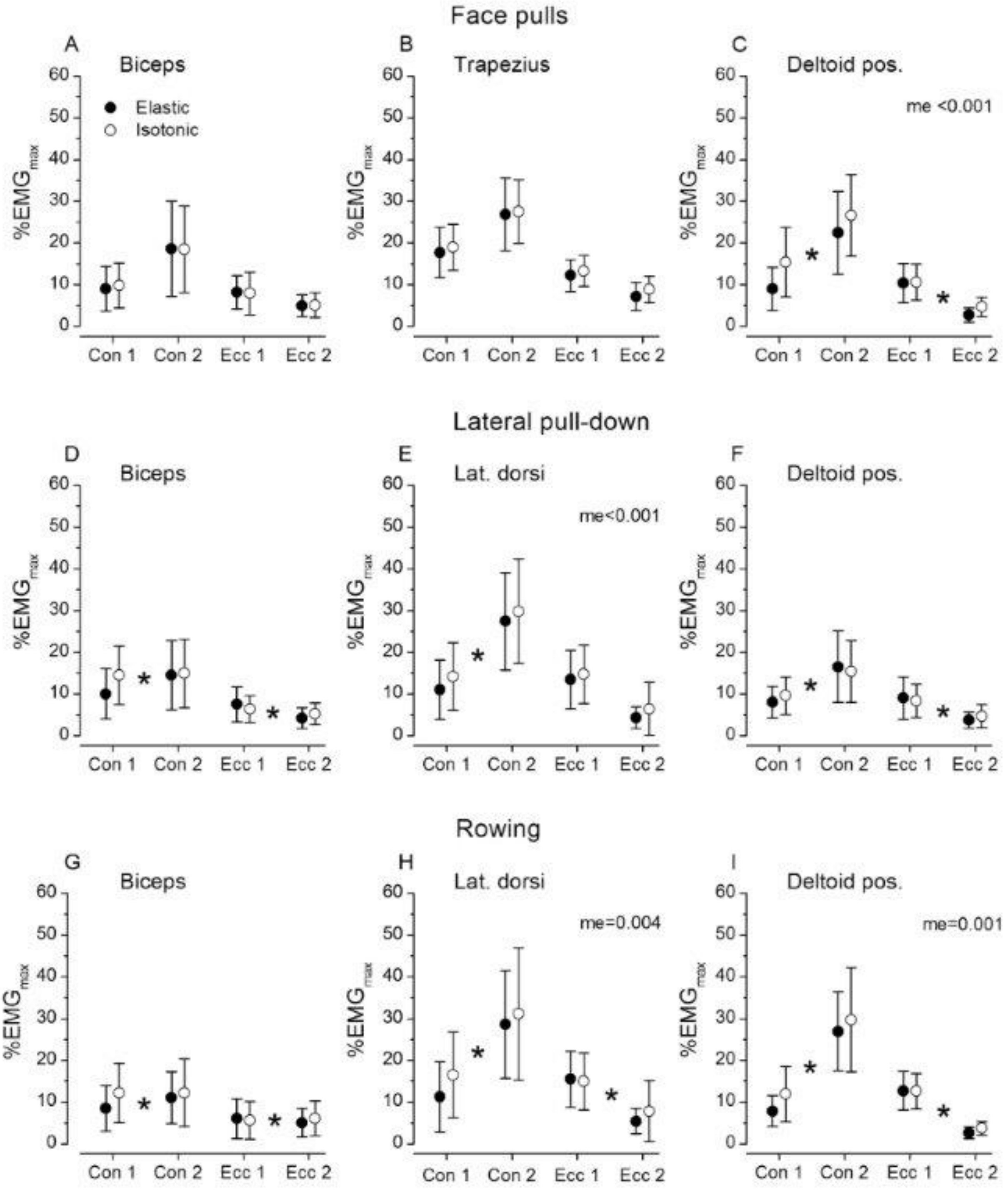


Figure 4. EMG levels in face pulls (A-C), lateral pull-down (D-F), and rowing (G-I), using elastic and isotonic resistance. P-values for main effects (me) of exercise modality are indicated on figures. An asterisk indicates that a significant interaction effect exist between con1 and con2, and ecc1 and ecc2, respectively.

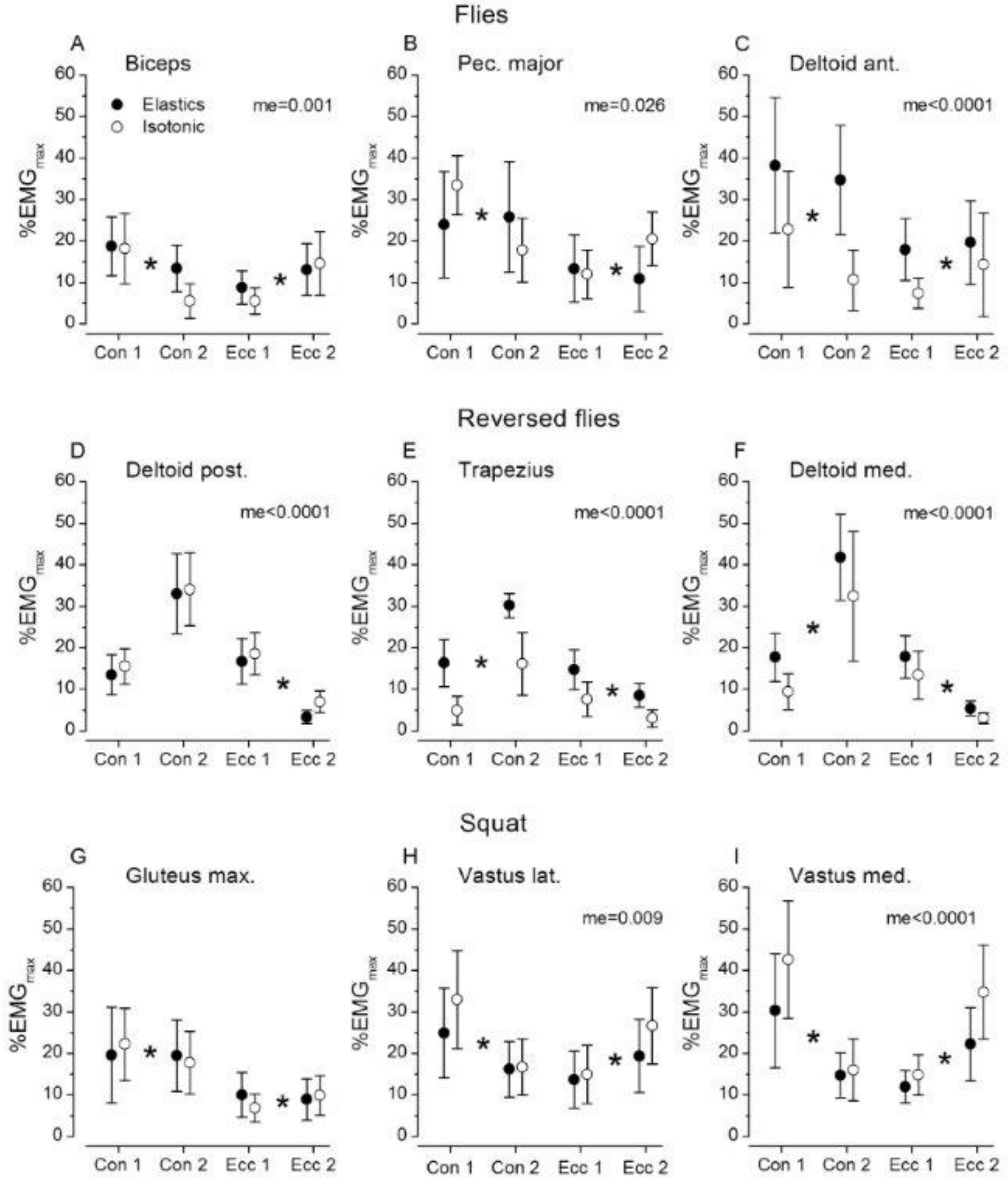


Figure 5. EMG levels in flies (A-C), reversed flies (D-F), and squat (G-I), using elastic and isotonic resistance. P-values for main effects (me) of exercise modality are indicated on figures. An asterisk indicates that a significant interaction effect exist between con1 and con2, and ecc1 and ecc2, respectively.

Discussion

Muscle activity levels were significantly higher in eight combinations when using isotonic resistance, and four when using elastic. In the remaining six combinations, no significant difference was found. The numerical difference was in most cases trivial, and the physiological difference in exercise outcome between isotonic and elastic resistance is likely to be small. In ACSM's latest position stand, intensities are recommended in 10 percentage point intervals, e.g. 60-70% of 1 RM for novices to intermediates (2009). Thus, differences in muscle activity less than 10% between elastic and isotonic resistance is not in the present study considered to have any practical relevance. It is evident when looking at these results that the difference in muscle activity during exercise with elastic resistance compared to isotonic is not systematic. Several studies in which elastic and isotonic resistance has been compared have shown no significant difference in muscle activity (Andersen et al., 2010; Calatayud et al., 2015; Jakobsen et al., 2012; Jakobsen et al., 2014). Brandt et al., (2013) found a higher muscle activity when using elastic resistance in hip abduction, but not hip adduction, and Sundstrup et al., (2012) found a higher muscle activity when using elastic resistance when performing abdominal crunches, compared to doing crunches in a machine (isotonic). In Sundstrup et al., (2014), however, a higher muscle activity was found when performing lunges with dumbbells compared to elastic bands. Thus, the variation in muscle activity between elastic and isotonic resistance across different exercises found in the present study is in line with previous studies.

For all muscles and exercises except biceps and trapezius during face pulls, significant interaction effects were found, i.e., the difference in muscle activity was affected by contraction phase. The interaction effects were commonly reflected by a higher muscle activity in con1 and ecc2 with isotonic resistance compared to elastic, while in con2 and ecc1 the muscle activity was more similar. An increased resistance created in the contraction phases where the elastic band is more stretched probably causes this. When the resistance in the band increases, the subject has to generate more force, and thus higher muscle activity levels are elicited. This tendency has also been observed in other studies where the objective was to find the knee angles at which muscle activity peaked during extension and flexion (Jakobsen et al., 2012; Jakobsen et al., 2014). As expected, muscle activity peaked towards the knee angles where the elastic band was stretched the most, whereas during isotonic resistance the peak occurred at different angles.

When interpreting the differences in muscle activity patterns between elastic and isotonic resistance, the biomechanical differences in execution of the exercises needs to be taken into consideration. In exercises where the execution with elastic and isotonic resistance was quite similar, such as face pulls, lateral pull-down and rowing, the differences in muscle activity were rather small. In flies, reversed flies, and squat, however, the execution was not identical, and this is reflected by far more observable differences in muscle activity levels. This is a result of the muscles working differently when the exercises are performed in different ways. For example, when performing flies with elastic resistance, the muscle activity for pectoralis major are higher in the con2 and ecc1 phases compared to isotonic resistance, while lower in the con1 and ecc2. When performing flies with dumbbells, a large moment arm is present during the con 1 and ecc2 phases, when holding the dumbbells with extended arms away from the body. As the dumbbells is moved towards each other above the chest, the moment arms is decreased and relatively little force is required to support the dumbbells, thus explaining the low muscle activity in the con2 and ecc1 phase. When using elastic bands, however, the con 2 and ecc1 are the phases in which the band is stretched the most, thus a higher amount of force is needed to press the handles against each other. For deltoideus anterior, $\%EMG_{max}$ was ~15 and ~25 percentage points higher when using elastic resistance during con1 and con2, respectively. A possible explanation could be the difference in shoulder flexion angle. When performing flies with elastic resistance, the subjects was standing with one foot in front of the other, leaning forward in order to counteract the backwards pull from the elastic band. This creates a greater shoulder flexion angle than seen when the subject is lying on the bench during isotonic resistance flies.

In reversed flies, the differences in execution were similar to flies, i.e., it was performed lying with isotonic resistance and standing with elastic. However, muscle activity levels did not differ in the same degree. For deltoideus posterior, muscle activity was quite similar, and for trapezius and deltoideus medius muscle activity levels were slightly higher in the con1 and con2 phases when using elastic resistance.

When performing squats, the muscle activation in vastus lateralis and medialis were higher with isotonic resistance in con1 and ecc2, while in con2 and ecc2 the difference was minimal. This indicates that despite being in the phases of contraction where the band was most stretched, the muscle activity was not higher compared to isotonic resistance. This could be caused by the fact that the knee angle was decreased in this phase, and as a result less force was required from the vastus lateralis and medialis. However, the 10 RM load used in squat with elastic resistance might not reflect the subjects' true 10 RM. During the process of identifying the 10 RM, several elastic bands had to be used to provide adequate load in squat, and the pressure felt when holding the bands around the shoulders became quite unpleasant for the subjects. Thus, the limiting factor was not leg strength, but the amount of discomfort the subject was willing to tolerate. However, perceived loading rated on the Borg CR10 scale was not significantly different between the two modalities.

The subjects in this study were healthy, without any pain at the time of data recording, and of relatively young age (25 years ± 2.5). However, it is reasonable to believe that the results would apply for other age groups as well. Sundstrup et al., (2014) found comparable muscle activation between isotonic and elastic resistance in both young and old people, with and without pain in the hips and knees. Moreover, Calatayud et al., (2015) found that when the same conditions are reproduced, one can expect similar increments in strength levels when using elastic or isotonic resistance in a exercise program with a duration of five weeks. This finding proves the assumption that similar muscle activity will have similar effects when the conditions otherwise are similar. For the present study, this implies that similar adaptations are likely to occur in the exercises where the difference in execution and muscle activity between elastic and isotonic resistance was small. A prerequisite is that the exercise intensity is matched. In the present study, the exercises intensity, as reflected by the %EMG_{max}, does not appear to be sufficient to elicit desirable physiological adaptations, such as increased strength and muscle mass. However, it has to be taken into consideration that the muscle activity-variable is a mean of RMS EMG, and is missing EMG data during 10% of the start and end of range of motion, thus muscle activity might have been sufficiently high if peak RMS EMG was used instead. To achieve a specific (or sufficient) level of muscle activity was, however, not an objective in this study.

Strengths and limitations

The length of the elastic bands was similar for all subjects. It is not unusual to standardize the length to each subject's height. If the length is equal for two persons, the resistance will be higher for the person with the longest limb, because this person is able to stretch the band further than a person with shorter limbs. Instead, the 10 RM test was used. The reliability of a multiple-repetition maximum test using eight repetitions was found to be excellent (Taylor and Fletcher 2012). However, the load was not measured when using elastic bands, and one cannot be sure that the loading was identical for elastic and isotonic resistance. Andersen et al., (2010) carried out a study where the load with elastic and isotonic resistance was objectively matched by using standardized lengths on the elastic bands. The manufacturer provided loads in kg for the different bands at different lengths (e.g., 150% and 200% of resting length). For isotonic resistance dumbbells with corresponding loads was used. No significant difference in muscle activity was found for the three exercises tested in that study. Thus, it would have been useful to measure the loads used with elastic resistance in the present study with a force sensor. In the exercises that were not identical, such as squat, it is likely that the load was higher when using isotonic resistance.

All testing was performed by the same person, thus electrode placement, exercise instructions, 10 RM assessment and maximal voluntary procedures was the same for all subjects. The order of exercises was not randomized, but standardized in the same order for both elastic and isotonic resistance. Thus, any effect of fatigue from the first exercises on the last ones would have been similar for both exercise modalities.

The exercises performed with elastic bands in this study can be performed anywhere by using a door as an anchor point. This makes the results relevant for therapists seeking exercises to provide in a home-based rehabilitation program, as well as for others who want to exercise at home.

Conclusion

During exercises performed in a similar way with matched load, comparable levels of muscle activity were found when using elastic and isotonic resistance during face pulls, rowing and lateral pull-down. In flies, reversed flies, and squat, muscle activity was affected by biomechanical differences in the execution of the exercise. Thus, if performed similarly with the same load, exercises with elastic resistance will have the same effect on strength gain as isotonic resistance, making elastic bands a feasible alternative to free weights. Elastic bands can be used more easily by patients, therapists, athletes, or just people in general who does not have the opportunity to use a free weights but wishes to benefit from strength exercise.

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