Muscle Activation and Perceived Loading During Rehabilitation Exercises: Comparison of Dumbbells and Elastic Resistance

Lars L. Andersen, Christoffer H. Andersen, Ole S. Mortensen, Otto M. Poulsen, Inger Birthe T. Bjørnlund, Mette K. Zebis

Background. High-intensity resistance training plays an essential role in the prevention and rehabilitation of musculoskeletal injuries and disorders. Although resistance exercises with heavy weights yield high levels of muscle activation, the efficacy of more user-friendly forms of exercise needs to be examined.

Objective. The aim of this study was to investigate muscle activation and perceived loading during upper-extremity resistance exercises with dumbbells compared with elastic tubing.

Design. A single-group, repeated-measures study design was used.

Setting. Exercise evaluation was conducted in a laboratory setting.

Participants. Sixteen female workers (aged 26–55 years) without serious musculoskeletal diseases and with a mean neck and shoulder pain intensity of 7.8 on a 100-mm visual analog scale participated in the study.

Measurements. Electromyographic (EMG) activity was measured in 5 selected muscles during the exercises of lateral raise, wrist extension, and shoulder external rotation during graded loadings with dumbbells (2–7.5 kg) and elastic tubing (Thera-Band, red to silver resistance). The order of exercises and loadings was randomized for each individual. Electromyographic amplitude was normalized to the absolute maximum EMG amplitude obtained during maximal voluntary isometric contraction and exercise testing. Immediately after each set of exercise, the Borg CR10 scale was used to rate perceived loading during the exercise.

Results. Resistance exercise with dumbbells as well as elastic tubing showed increasing EMG amplitude and perceived loading with increasing resistance. At the individually maximal level of resistance for each exercise—defined as the 3 repetitions maximum—normalized EMG activity of the prime muscles was not significantly different between dumbbells (59%–87%) and elastic tubing (64%–86%). Perceived loading was moderately to very strongly related to normalized EMG activity (r=.59–.92).

Limitations. The results of this study apply only for exercises performed in a controlled manner (ie, without sudden jerks or high acceleration).

Conclusions. Comparably high levels of muscle activation were obtained during resistance exercises with dumbbells and elastic tubing, indicating that therapists can choose either type in clinical practice. The Borg CR10 can be a useful aid in estimating intensity of individual rehabilitation protocols.

L.L. Andersen, PhD, is Researcher, National Research Centre for the Working Environment, Lersø Parkalle 105, DK 2100 Copenhagen, Denmark. Address all correspondence to Dr Andersen at: LLA@NRCWE.DK.

C.H. Andersen, MSc, is a PhD student at National Research Centre for the Working Environment.

O.S. Mortensen, MD, PhD, is Researcher, National Research Centre for the Working Environment, and Department of Occupational and Environmental Medicine, Bispedjerg University Hospital, Copenhagen, Denmark.

O.M. Poulsen, DrMedSci, is Director of Research, National Research Centre for the Working Environment.

I.B.T. Bjørnlund, BSc (Physiotherapy), is Teacher in Physiotherapy, Faculty of Physiotherapy, Metropolitan University College, Copenhagen, Denmark.

M.K. Zebis, PhD, is Researcher, National Research Centre for the Working Environment.

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More than half a century ago DeLorme[1] recommended progressive resistance training for rehabilitation of injured servicemen. Today, high-intensity resistance training has become an essential part of various rehabilitation protocols.[2] For instance, resistance training is used effectively in rehabilitation of work-related neck and shoulder pain,[3,4] rotator cuff injury,[5,6] Achilles tendinopathy,[7] poststroke hemiplegia,[8] and postoperative weakness in elderly patients.[9]

A key ingredient of strengthening protocols is *training intensity*, defined as the percentage of maximal voluntary force exerted. Electromyography (EMG) is commonly used to measure the level of muscle activation and provides a rough estimate of exercise intensity for specific muscles involved in the movement.[10–15] Training intensities of 60% and higher generally are recommended to obtain the desired physiological adaptations.[16] To yield high levels of muscle activation, resistance training usually is performed on machines or with free weights.[10,17] In clinical practice and for home-based rehabilitation, conventional resistance training devices may not always be feasible. Thus, the effectiveness of alternative exercise methods should be investigated.

Strengthening exercises with elastic resistance have been shown to be a feasible alternative to heavy weights in certain situations.[18,19] The material properties of commercially available elastic tubing theoretically allows for efficient resistance exercise.[20] However, although some studies have demonstrated high levels of muscle activation for specific muscles using elastic resistance,[13,15] other studies have shown low to medium levels of activation for most of the involved muscles.[15,21–23] Overall, these studies indicate practical difficulties in determining the appropriate exercise intensity using elastic resistance. Thus, there is a need to further investigate whether high levels of muscle activation similar to those achieved with traditional devices, such as dumbbells, can be obtained with elastic resistance devices.

Self-selected loadings in resistance training generally are lower than recommended—below 60% of the maximal dynamic load.[24–27] Although the repetitions maximum test is recommended to determine training intensity,[28] this test is performed to local muscle exhaustion, which may be inconvenient in patients with pain who are undergoing rehabilitation. Patient-report rating scales of exercise intensity may be more appropriate in clinical practice. The Borg CR10 scale has been widely used for rating the perceived intensity of various physiological experiences, such as physical exertion.[29] Thus, it would be relevant to investigate whether perceived loading rated on the Borg CR10 scale is related to the level of muscle activation.

The aim of the present study was to investigate the level of muscle activation (EMG) and perceived loading (Borg CR10 scale) during graded rehabilitation exercises using dumbbells in comparison with elastic resistance. We hypothesized that the levels of muscle activation and perceived loading are similar when comparing elastic resistance with dumbbells. Furthermore, we hypothesized that perceived loading is related to the level of muscle activation.

Method

Participants

The study was performed in Copenhagen, Denmark. A group of 16 women (41±9.6 years; 168±4.9 cm, 64.5±11.0 kg) with primarily sedentary jobs (office workers, laboratory technicians) were recruited on a voluntary basis for the study. Exclusion criteria were clinically assessed subacromial impingement syndrome, anamnestic history of disk prolapse, rheumatoid arthritis, or other serious musculoskeletal disorders. None of the recruited participants met these exclusion criteria. Musculoskeletal pain (100-mm visual analog scale) during the last 3 months was 7.8±19 mm (neck/shoulder), 5.4±15 mm (forearm), and 11±17 mm (low back) (mean ± SD). Complete testing was performed on all 16 participants with both elastic tubing and dumbbells during the exercises described below.

All participants were informed about the purpose and content of the project and gave written informed consent to participate in the study, which conformed to the Declaration of Helsinki and was approved by the local ethical committee (HC-2008-103).

Maximal Voluntary Isometric Contraction

Prior to the dynamic exercises described below, maximal voluntary isometric contractions (MVICs) were performed according to standardized procedures during neck extension, shoulder abduction, shoulder external rotation, and wrist extension to induce a maximal EMG response of the respective muscles.[30] Two MVICs were performed for each muscle, and the trial with the higher EMG response was used for normalization

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Table 1.
Comparison of Force Levels in Kilograms Between the Thera-Band Elastic Tubing (Range of 125%–150% Elongation of Resting Length) and Dumbbells Used in the Present Study[a]

Color	Elastic Tubing Range	Dumbbells
Red	2.0–2.2	2.0
Green	2.6–3.0	3.0
Blue	3.7–4.1	4.0
Black	5.0–5.6	5.0
Blue+red	5.7–6.3	6.25
Silver	6.9–7.8	7.5

[a] Thera-Band values are provided by the manufacturer.

of the peak EMG amplitude in the rehabilitation exercises. Participants were instructed to gradually increase muscle contraction force toward maximum over a period of 2 seconds, sustain the MVIC for 3 seconds, and slowly release the force. Verbal encouragement was given during all trials.

Exercise Equipment

Thera-Band elastic tubing* of different resistances (red, green, blue, black, and silver) were used. Handle-to-handle length of the elastic tubing was individually adjusted according to the following formula: Individual height minus 10 cm for the lateral raise and external rotation exercises. For the wrist extension exercise, the length of the tubing was set to half of the table height. During pilot testing, we found rather large differences in muscle activation and perceived loading between black and gray resistances. Thus, an intermediate resistance consisting of combined blue and red tubing was made for the further experiments. Thus, a total of 6 resistance levels were used. The material properties of Thera-Band elastic tubing have been described previously.[20,31] Correspondingly, standard iron dumbbells of 2, 3, 4, 5, 6.25, and 7.5 kg were used. A comparison of resistance in kilograms between the dumbbells and elastic tubing used in the present study is given in Table 1.

Exercise Description

All exercises were performed in a slowly controlled manner—lifting (~1.5 seconds) and lowering (~1.5 seconds) without sudden jerks or acceleration—for 3 consecutive repetitions. The order of exercises and loadings was randomized for each participant, and each set of exercise was initiated every 1.5 minutes. Participants were familiarized with the exercises on a separate day prior to testing. Three common rehabilitation exercises were chosen; one with a large range of motion (lateral raise), one with a small range of motion (wrist extension), and one involving joint rotation (external rotation).

In the lateral raise exercise (Fig. 1, left), the participants stood erect holding the dumbbells or tubing handles to the side and abducted the shoulder joints until the upper arms were slightly above horizontal. The elbows were in a static, slightly flexed position (~5°) during the entire range of motion. During this exercise, the elastic tubing was stretched to slightly more than twice its resting length (~125%–150% more than resting length).

In the wrist extension exercise (Fig. 1, middle), the participants rested their forearm on a table while holding the dumbbell or tubing handle in the same hand using a pronated grip. The elastic tubing was prestretched to twice its resting length. The starting position was from a flexed wrist. The participants then performed a wrist extension through a full range of motion.

In the external rotation exercise using elastic tubing (Fig. 1, upper right), the participants stood erect while holding the elbow at 90 degrees, close to the side. The starting position was with the forearm in front of the body, and the elastic tubing was parallel to the frontal plane. The elastic tubing was attached to a door handle and prestretched to twice its resting length. The participants then performed an external rotation through a full range of motion.

In the external rotation exercise using a dumbbell (Fig. 1, lower right), the participants lay on the nondominant side of the body while holding the dominant elbow at a 90-degree angle, close to the side. The starting position was with the forearm in front of the body. The participants then performed an external rotation through a full range of motion.

Perceived Loading

Immediately after each set of exercise, the Borg CR10 scale[29] was used to rate perceived loading of the respective muscle groups during the exercise. The meaning of the scale was carefully explained to each individual prior to testing.

EMG Signal Sampling and Analysis

Electromyography signals were recorded from the mid-portion of the splenius capitis, upper trapezius, medial deltoid, infraspinatus, and extensor digitorum communis muscles. A

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* The Hygenic Corp, 1245 Home Ave, Akron, OH 44310-2575.

Figure 1.
Illustration of the resistance exercises with elastic tubing (top) and dumbbells (bottom). The exercises are lateral raise (left), wrist extension (middle), and external rotation (right) exercises.

bipolar surface EMG configuration (Neuroline 720 01-K[†]) and an interelectrode distance of 2 cm were used. Before affixing the electrodes, the skin of the respective area was prepared with scrubbing gel (Acqua gel[‡]) to effectively lower the impedance to less than 10 kΩ. Electrode placement followed the SENIAM recommendations.[32] The EMG electrodes were connected directly to small preamplifiers located near the recording site. The raw EMG signals were led through shielded wires to instrumental differentiation amplifiers, with a bandwidth of 10 to 500 Hz and a common mode rejection ratio better than 100 dB, sampled at 1,000 Hz using a 16-bit A/D-converter (DAQ Card-Al-16XE-50[§]) and recorded on computer via a laboratory interface (CED 1401, Spike2 software[‖]). Representative samplings of raw EMG signals from one of the participants during the lateral raise exercise with elastic tubing and dumbbells, respectively, are shown in Figure 2.

During later analysis, all raw EMG signals obtained during MVICs and during the dumbbell and elastic tubing exercises were digitally filtered, consisting of: (1) high-pass filtering at 10 Hz[33] and (2) a moving root-mean-square (RMS) filter of 500 milliseconds. For each individual muscle, peak RMS EMG amplitude of the 3 repetitions performed at each level was determined, and the average value of these 3 repetitions was normalized to the absolute maximum EMG amplitude obtained during maximal voluntary isometric contraction and exercise testing. High levels of muscle activation were defined in the present study as normalized EMG amplitude above 60%.[10,16]

[†] Medicotest A/S, Rugmarken 10, 3650 Ølstykke, Denmark.

[‡] Meditec SRL, Via Micheli 9 S. Polo Di Torrile, 43056 Torrile, Parma, Italy.

[§] National Instruments Corp, 11500 N Mopac Expwy, Austin, TX 78759-3504

[‖] Cambridge Electronic Design Ltd, Unit 4, Science Park, Milton Rd, Cambridge, CB4 0FE United Kingdom.

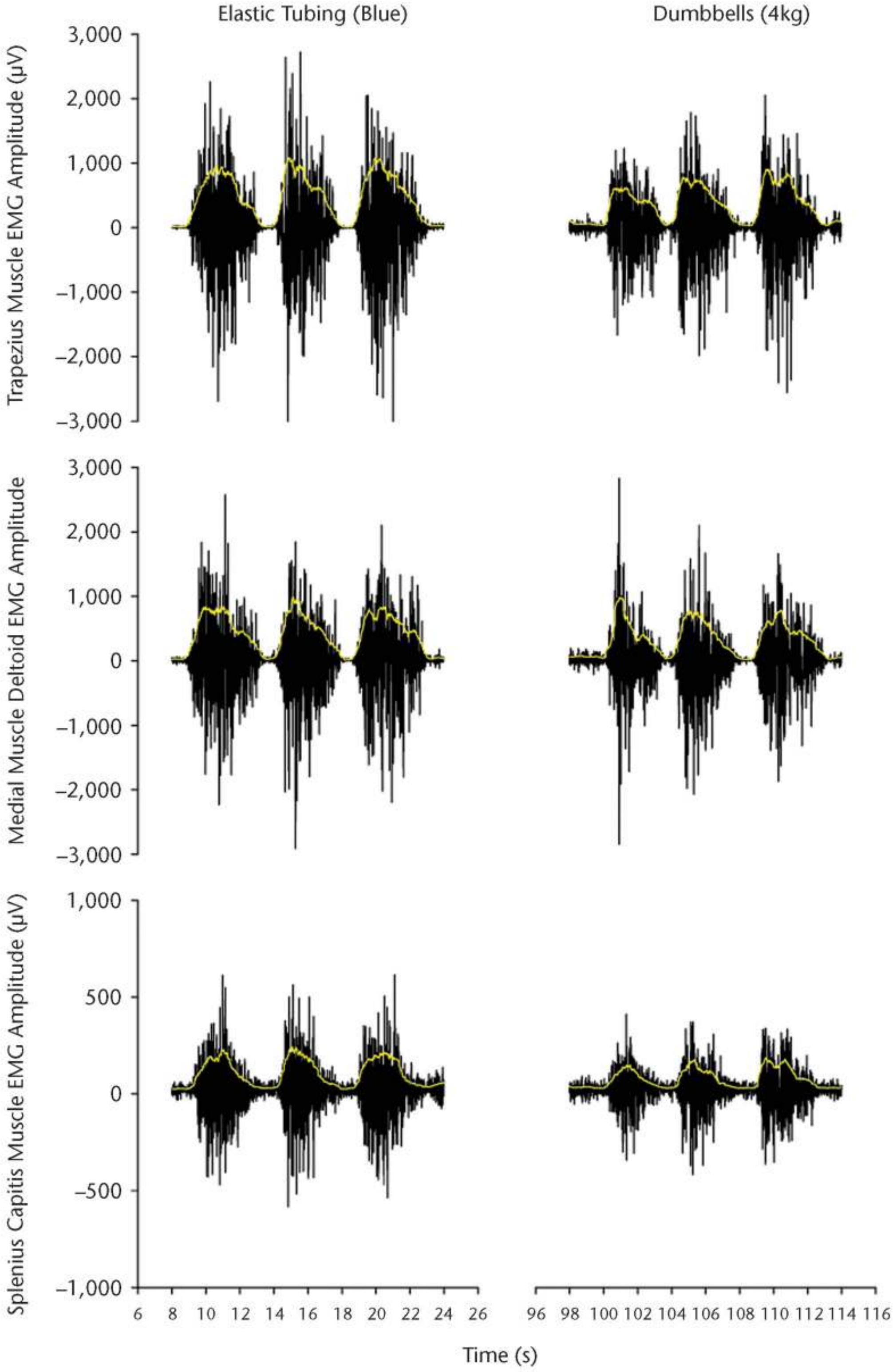

Figure 2.

Raw recording of electromyography (EMG) signals during 3 repetitions of lateral raise exercise with elastic tubing (left) and dumbbells (right) in the trapezius (top), medial deltoid (middle), and splenius capitis (bottom) muscles. The root-mean-square EMG recording is overlaid (yellow tracing) on the raw EMG recording.

Table 2.
Perceived Loading (Borg CR10 Scale) and Muscle Activation (Normalized Electromyography [EMG] Amplitude) for the Splenius Capitis, Trapezius, Medial Deltoid, Infraspinatus, and Extensor Digitorum Communis Muscles at Each Absolute Resistance Level With Elastic Tubing (Red-Silver) and Dumbbells (2–7.5 kg) During Lateral Raise, Wrist Extension, and External Rotation Exercises[a]

			Normalized EMG Amplitude (%)									
	Perceived Loading		Trapezius Muscle		Medial Deltoid Muscle		Splenius Capitis Muscle		Extensor Digitorum Communis Muscle		Infraspinatus Muscle	
Exercise	**Elastic Tubing**	**Dumbbells**	**Elastic Tubing**	**Dumbbells**	**Elastic Tubing**	**Dumbbells**	**Elastic Tubing**	**Dumbbells**	**Elastic Tubing**	**Dumbbells**	**Elastic Tubing**	**Dumbbells**
Lateral raise												
Red/2 kg	1.7±0.2	1.7±0.2	53±3.2	46±3.2	66±3.1	63±2.8	24±3.0	21±2.8	27±2.6	22±2.3	19±3.8	17±4.3
Green/3 kg	2.7±0.3	2.9±0.3	63±3.6	60±3.2	72±3.0	70±2.8	35±4.0	31±3.9	29±1.8	32±3.0	26±4.2	23±4.0
Blue/4 kg	3.8±0.4	4.2±0.4	75±3.4	72±3.2	81±2.6	80±2.5	47±4.2	44±3.9	38±2.8	45±3.7	31±4.0	32±4.5
Black/5 kg	**4.6±0.5**	**5.2±0.4**	**83±3.1**	**84±3.0**	**82±3.0**	**88±2.5**	**58±4.6**	**62±5.3**	**50±2.5**	**61±5.4**	**36±4.0**	**42±4.9**
Blue+red/ 6.25 kg	7.0±0.7	6.9±0.6	78±3.3	83±3.0	77±3.2	83±3.2	63±4.9	66±3.6	56±3.8	65±4.4	45±4.7	45±5.2
Silver/7.5 kg	8.2±0.7	8.5±0.6	75±3.6	84±4.0	73±2.7	80±2.0	62±3.9	69±4.3	59±4.0	69±4.7	49±4.7	51±4.6
Wrist extension												
Red/2 kg	1.7±0.3	1.9±0.2	5±0.8	5±0.9	3±0.4	3±0.5	6±0.8	6±0.7	55±4.6	56±6.0	5±0.5	4±0.5
Green/3 kg	2.3±0.2	2.5±0.3	5±1.0	6±1.1	4±0.6	4±1.2	7±1.1	6±0.9	61±5.2	66±4.5	10±1.6	8±1.1
Blue/4 kg	3.5±0.4	3.7±0.4	6±1.1	7±1.2	4±0.8	5±0.9	8±1.2	8±1.5	69±4.3	74±4.7	11±1.5	12±1.4
Black/5 kg	5.0±0.6	5.5±0.5	6±0.9	7±1.2	5±0.7	6±1.2	11±2.3	11±2.0	70±3.8	80±4.5	14±1.7	19±2.5
Blue+red/ **6.25 kg**	5.5±0.6	**6.5±0.6**	8±1.5	**10±2.0**	6±1.0	**7±0.8**	13±2.1	**16±2.4**	76±4.3	**81±4.0**	19±2.5	**22±2.3**
Silver/7.5 kg	**6.5±0.7**	8.3±0.7	**8±1.3**	16±2.2	**7±1.3**	12±1.7	**16±2.2**	21±3.0	**78±3.6**	80±4.5	**24±2.6**	32±2.5
External rotation												
Red/2 kg	1.5±0.2	2.0±0.2	5±0.7	5±0.7	5±0.9	9±1.3	8±2.1	17±2.7	22±2.9	24±2.4	36±4.4	41±4.5
Green/3 kg	2.5±0.2	3.3±0.3	7±1.1	8±1.1	6±0.9	14±2.7	9±1.7	20±2.2	27±3.1	35±4.3	44±4.7	55±3.4
Blue/**4 kg**	3.7±0.4	**5.5±0.6**	9±1.4	**12±2.1**	10±1.7	**29±4.2**	10±1.8	**25±2.2**	32±3.2	**49±5.1**	59±4.1	**68±2.4**
Black/5 kg	**5.2±0.5**	7.2±0.7	**13±2.4**	14±2.5	**21±3.5**	35±3.4	**13±1.9**	30±4.4	**43±2.9**	58±4.5	**73±3.6**	69±3.9
Blue+red/ 6.25 kg	7.2±0.8	7.6±0.7	15±2.7	14±2.7	30±4.1	41±4.4	19±2.0	33±3.3	52±4.1	62±5.3	71±4.1	70±3.9
Silver/7.5 kg	8.3±0.7	8.8±0.7	18±3.7	16±2.4	35±4.5	45±4.3	27±2.8	35±3.7	56±4.2	63±5.2	75±4.2	72±3.1

[a] Values are expressed as mean ± standard error. The group median resistance at "max" is marked in bold for each exercise.

Data Analysis

A 2-way (2 × 6) repeated-measures analysis of variance (ANOVA) (SAS version 9[#]) was used to determine whether differences existed between dumbbells and elastic tubing. Factors included in the model were type (dumbbells and elastic tubing) and resistance (6 resistance levels for dumbbells and elastic tubing, respectively), as well as type × resistance interaction. Dependent variables were perceived loading (Borg CR10 scale) and muscle activation (normalized EMG amplitude for each of the 5 muscles) (ie, 6 possible outcomes for each of the 3 exercises). To avoid mass significance due to multiple primary analyses, only 8 preplanned ANOVAs were performed—Borg CR10 scale for all 3 exercises; EMG activity of the upper trapezius, splenius, and medial deltoid muscles for the lateral raise exercise; EMG activity of extensor digitorum communis muscle for the wrist extension exercise; and EMG activity of the infraspinatus muscle during shoulder external rotation. Furthermore, the critical P value of the primary analyses was set to .01.

When a significant main effect was found, *post hoc* comparisons were made to locate differences. Results are reported for both absolute (Tab. 2) and relative (Fig. 3) levels of resistance. Absolute levels of resistance refer to the color of the tubing and weight of the dumbbell. For determination of the relative level of resistance, the highest voluntary resistance of each participant—the 3 repetitions maximum (RM)—was set to level 0 (denoted “max” in Fig. 3). Likewise, each decrement and increment, respectively, in relative resistance level corresponded to a lower (denoted “submax” in Fig. 3) and higher (denoted “supramax” in Fig. 3) resistance in either dumbbell weight or color of the tubing. To avoid mass significance of *post hoc* tests, the critical P value was set to .01, and all values are reported as group means ± standard error unless otherwise stated.

Finally, Spearman correlation coefficients were calculated to determine the relationship among: (1) perceived loading and EMG activity, (2) actual loading and EMG activity, and (3) actual and perceived loading (submaximal and maximal loadings) (Tab. 3). The strength of the relationship was defined as very weak (r=.0–.2), weak (r=.2–.4), moderate (r=.4–.7), strong (r=.7–.9), or very strong (r=.9–1.0).

A difference of less than 10% in normalized EMG amplitude between dumbbells and elastic tubing was considered clinically insignificant. This value was based on general strength training literature, where recommendations often are given in increments of 10 percentage points (eg, “it is recommended that novice to intermediate individuals train with 60–70% of 1 RM”[16(p690)]). *A priori* power analysis showed that 16 participants in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 10% and a type I error probability of 1%, assuming a standard deviation of 10% based on previous research in our laboratory.[10]

Results

Group mean ± standard error values at absolute resistance levels are presented in Table 2, and group mean ± standard error values at relative resistance levels are shown in Figure 3. Note that “absolute resistance” refers to the color of the tubing and weight of the dumbbell, whereas “relative resistance” refers to the resistance level relative to “max.” Thus, the group mean values of Table 2 and Figure 3 can differ.

Perceived Loading (Borg CR10 Scale)

A priori hypothesis testing of main effects showed a significant resistance effect for perceived loading in the lateral raise (F=32, P<.0001), wrist extension (F=49, P<.0001), and external rotation (F=38, P<.0001) exercises (ie, perceived loading increased with increasing resistance during all 3 exercises with both dumbbells and elastic tubing). Furthermore, a trend toward a type effect was observed for external rotation only (F=6.2, P=.04) (ie, perceived loading during elastic tubing tended to be lower compared with dumbbells [Δ Borg CR10 scale score=0.98±0.40, P=.04]). The type × resistance interaction was not significant for any of the examined exercises.

Perceived loading at the individual “max” level with dumbbells versus elastic tubing, respectively, was not significantly different (5.5±0.6 versus 5.2±0.7 for lateral raise, 6.4±0.7 versus 6.5±0.8 for wrist extension, and 5.2±0.6 versus 5.2±0.7 for external rotation) (Fig. 3A).

Muscle Activation (EMG)

A priori hypothesis testing of main effects showed a significant resistance effect for EMG activity of the upper trapezius muscle (F=20, P<.0001), medial deltoid muscle (F=10, P<.0001), and splenius capitis muscle (F=37, P<.0001) during the lateral raise exercise; for EMG activity of the extensor digitorum communis muscle (F=19, P<.0001) during the wrist extension exercise; and for EMG activity of the infraspinatus muscle (F=38, P<.0001) during the external rotation exercise. Thus, normalized EMG amplitude of the prime muscles generally increased with increasing absolute resistance (Tab. 1) and relative resistance (Figs. 3B–F) for both dumbbells and elastic tubing during all 3 exercises. There were no significant type effects for any of the prime muscles (ie, no dif-

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[#] SAS Institute Inc, PI Box 8000, Cary, NC 27513

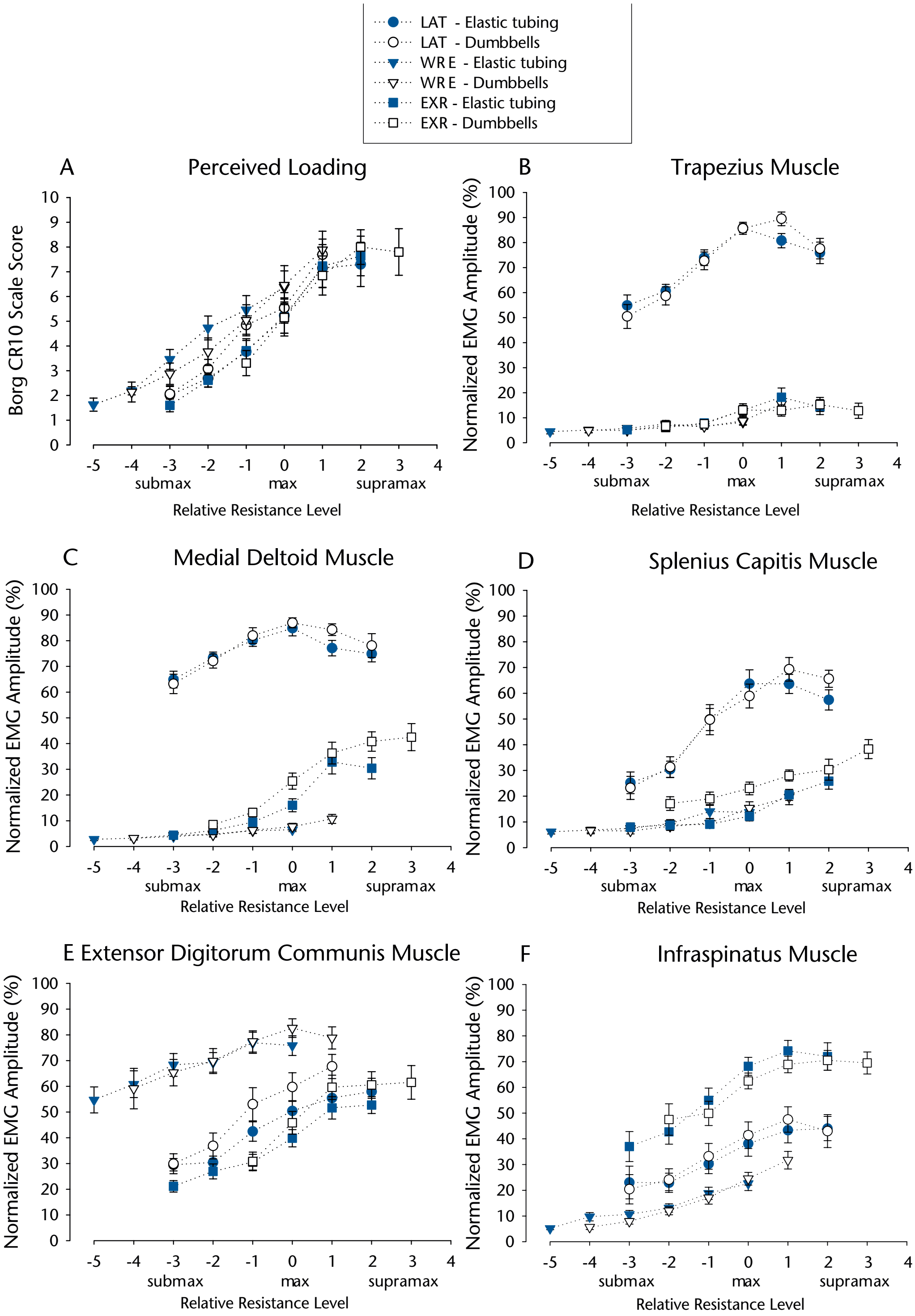

Figure 3.

Perceived loading rated on the Borg CR10 scale (A) and normalized electromyography (EMG) amplitude of the trapezius (B), medial deltoid (C), splenius capitis (D), extensor digitorum communis (E), and infraspinatus (F) muscles during the different exercises and relative loadings with dumbbells (open marks) and elastic tubing (blue marks). LAT=lateral raise exercise, WRE=wrist extension exercise, EXR=external rotation exercise, submax=submaximal, max=maximal, and supramax=supramaximal.

Table 3.
Spearman Correlation Coefficient Among Perceived Loading, Actual Loading, and Normalized Electromyography (EMG) Amplitude of the Prime Muscles During Lateral Raise, Wrist Extension, and External Rotation Exercises[a]

Measure		Lateral Raise			Wrist Extension		External Rotation	
		Trapezius Muscle	Medial Deltoid Muscle	Actual Loading	Extensor Digitorum Communis Muscle	Actual Loading	Infraspinatus Muscle	Actual Loading
Perceived loading	Elastic tubing	.76±.09	.65±.12	.83±.09	.59±.10	.92±.02	.79±.09	.85±.07
	Dumbbells	.83±.05	.65±.15	.89±.05	.58±.18	.96±.02	.92±.04	.99±.01
Actual loading	Elastic tubing	.93±.04	.75±.07		.70±.10		.93±.05	
	Dumbbells	.94±.03	.78±.12		.71±.16		.83±.11	

[a] Values are expressed as mean ± standard error.

ference between dumbbells and elastic resistance). The type × resistance interaction was not significant for any of the examined exercises.

Normalized EMG amplitude at the individual "max" level with dumbbells versus elastic tubing, respectively, was 86%±2.4% versus 86%±1.8% for the upper trapezius muscle (Fig. 3B), 87%±1.9% versus 85%±3.0% for the medial deltoid muscle (Fig. 3C), and 59%±4.6% versus 64%±5.4% for the splenius capitis muscle during the lateral raise exercise (Fig. 3D). During the wrist rotation exercise, the normalized EMG amplitude was 83%±3.6% versus 76%±3.8% for the extensor digitorum communis muscle (Fig. 3E) and 63%±3.1% versus 68%±3.5% for the infraspinatus muscle during external rotation exercise (Fig. 3F).

Relationship Among Main Variables

There was a moderate to very strong relationship among perceived loading (Borg CR10 scale), actual loading, and normalized EMG amplitude of the prime muscles (Tab. 2).

Discussion

The main finding of this study was the comparable high level of muscle activation during resistance exercise with elastic tubing and dumbbells, indicating that both types of exercise can be used equally during rehabilitation. Perceived loading and the level of muscle activation increased with increased external resistance. The practical relevance of these results is discussed below.

Relevance for Neck and Shoulder Rehabilitation

Approximately half of female office workers reports frequent trouble in the neck and shoulder area,[34] which often is paralleled by tenderness and tightness of the upper trapezius muscle.[35] Exercises to target the upper trapezius muscle are essential in rehabilitation of work-related neck and shoulder muscle pain. We have previously reported marked reductions of pain symptoms in women with trapezius muscle myalgia in response to high-intensity specific strength training.[4,10] In that study, several exercises—lateral raise and shrugs—yielded high levels of trapezius muscle activation. However, the lateral raise exercise required only one fifth of the nominal load used during the shrug exercise, making it more practical. The present study elaborated on these findings by showing similarly high levels of trapezius muscle activation using elastic tubing compared with dumbbells.

High levels of trapezius muscle activation were seen at relative resistance level −2 and higher (Fig. 3B). For example, if one individual can perform a 3 RM ("max") with black elastic tubing, then both blue (level −1) and green (level −2) resistances induce sufficiently high levels of trapezius muscle activation. Based on these results, we suggest individual neck and shoulder rehabilitation protocols to be initiated at 2 levels below the 3 RM, corresponding to a perceived loading of approximately 3 on the Borg CR10 scale, and then gradually progress toward higher loads. Interestingly, supramaximal loads did not appear to further facilitate activation of the trapezius muscle (Fig. 3B), likely due to a shorter range of motion. Thus, the exercises should be executed in a controlled manner through a full range of motion.

The splenius capitis muscle is one of the neck muscles involved in extension and rotation of the cervical spine. This muscle can be assessed by surface EMG activity in the posterior triangle of the neck in the space between the upper trapezius and sternocleidomastoid muscles. Isometric resistance training of the neck muscles has been shown to be effective in decreasing nonspecific neck pain.[36] The lateral raise exercise—both with dumbbells and elastic tubing—induced fairly high levels of splenius capitis muscle activity

(59%–64% at 3 RM, Fig. 3D), despite a static neck position during movement of the shoulder joint. This requirement for static neck stabilization when performing exercises of the shoulder girdle at high intensities indicates that specific isometric neck exercises used in a previous study[36] may be redundant. Future research involving indwelling electrodes should be performed to determine the level of muscle activation in the deep neck muscles during high-intensity resistance exercises involving shoulder girdle movement compared with specific isometric neck exercises.

Relevance for Rehabilitation of Forearm Muscle Pain

Intensive use of a computer mouse and keyboard has been established as a risk factor for development of forearm pain.[37] The extensor digitorum communis muscle is one of the major forearm muscles activated during computer work[38,39] and is highly susceptible to fatigue.[40] It is likely that the etiology of computer-related tenderness of the forearm muscles is similar to that of trapezius muscle myalgia (ie, overload of low-threshold motor units due to prolonged repetitive and monotonous work tasks[41,42]), indicating that these muscles may respond positively to specific resistance training. The present study showed equally high levels of extensor digitorum communis muscle activation during wrist extension exercises using dumbbells and elastic tubing (76%–83% at 3 RM, Fig. 3E). High levels of muscle activation were obtained at relative resistance level −4 and higher, corresponding to a perceived loading of 2 to 3 on the Borg CR10 scale, which may be a starting point for rehabilitation of tender forearm muscles.

Relevance for Rotator Cuff Injuries

Rotator cuff injuries are frequent in athletes in sports involving throwing, physical rehabilitation—including high-intensity resistance training—is recommended as the primary treatment before surgery is considered.[5] Although most of the rotator cuff muscles are covered by superficial muscles, the infraspinatus muscle can be assessed with surface EMG at the point below the posterior deltoid muscle lateral to the trapezius muscle. In the present study, relevant high levels of infraspinatus muscle activity were obtained with both dumbbells and elastic resistance (63%–68% at 3 RM, Fig. 3F). Similar levels of infraspinatus muscle activity during external rotation using a specially built pulley system with an attached weight have been reported previously.[43] High levels of muscle activation were obtained only at relative resistance level 0 and at supramaximal loadings, corresponding to a perceived loading of 5 and higher on the Borg CR10 scale. Thus, compared with the 2 other exercises of the present study, relatively high loadings are needed to obtain a high level of muscle activation during shoulder external rotation. Although very high intensities are not recommended during the initial phases of rehabilitation, such intensities may be necessary during later stages to ensure high levels of muscle activation.

Perceived Loading

Although EMG is commonly used in scientific experiments to analyze the level of muscle activation during specific exercises, only a few therapists have this opportunity. In addition, RM tests can be highly unpleasant and may be inappropriate in clinical practice. The present study showed that perceived loading rated on the Borg CR10 scale can be a helpful tool in determining the desired training intensity. For most of the investigated exercises, the 3 RM corresponded to 5 to 6 on the Borg CR10 scale. It should be noted that perceived loading was rated after 3 repetitions and that several consecutive repetitions leading to muscular fatigue may cause different ratings. Thus, for comparison with the present results, perceived loading should be rated in the nonfatigued state after only a few repetitions of the full set.

Methodological Considerations

The present study showed clear similarities between dumbbells and elastic tubing with regard to muscle activation and perceived loading during graded resistance exercise. Although not specifically investigated in this study, some differences also may exist. Whereas dumbbells provide isotonic resistance, elastic resistance increases linearly with elongation of the material.[20] Nevertheless, joint torque curves of elastic resistance training mimic isotonic training (eg, torque is increased similarly during shoulder abduction from 0° to 90° due to elongation of the material and increased lever arm length, respectively).[31]

Furthermore, it should be noted that all exercises were performed in a controlled manner and that differences between elastic tubing and dumbbells may exist during more explosive movements. Whereas the inertia of the dumbbell results in increased total moment of force during accelerative movements, the inertia of the elastic tubing is negligible. Thus, the results of the present study apply only for exercises performed according to general recommendations of basic strength training and rehabilitation (ie, in a controlled manner without sudden jerks or acceleration).

Although some accommodation comes from prestretching of the elastic tubing, as few as 20 repetitions appear to stabilize the material.[20] Because all elastic tubings were stretched several times during pilot testing in the present study, it is unlikely that the material properties were changed during actual testing.

With the use of surface EMG, there is an inherent risk of cross talk from neighboring muscles. Even though a relatively short inter-electrode distance of 2 cm was used, it is possible that EMG recordings from the splenius and infraspinatus muscles may have been affected by surrounding muscles to some extent. To our knowledge, the optimal inter-electrode distance for minimizing cross talk while retaining signal amplitude has not been determined for these particular muscles.

Conclusion

Comparable high levels of muscle activation were obtained during resistance exercises with dumbbells and elastic tubing, indicating that therapists can choose either type in clinical practice. The Borg CR10 can be a useful aid in estimating the proper intensity of individual rehabilitation protocols.

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