Evaluation of Muscle Activity During a Standardized Shoulder Resistance Training Bout in Novice Individuals

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Abstract

Jakobsen, MD, Sundstrup, E, Andersen, CH, Zebis, MK, Mortensen, P, and Andersen, LL. Evaluation of muscle activity during a standardized shoulder resistance training bout in novice individuals. J Strength Cond Res 28(9): 2515–2522, 2012—Momentary fatigue is an important variable in resistance training periodization programs. Although several studies have examined neuromuscular activity during single repetitions of resistance training, information is lacking in regard to neuromuscular fatigue indices throughout a full resistance training bout. The purpose of this study was to evaluate muscle activity during a shoulder resistance training bout with 15 repetitions maximum (RM) loadings in novice individuals. Twelve healthy sedentary women (age = 27–58 years; weight = 54–85 kg; height = 160–178 cm) were recruited for this study. Normalized electromyographic (nEMG) activity and median power frequency (MPF) of the upper, medial, and lower trapezius; the medial deltoid, infraspinatus, and serratus anterior was measured during 3 sets of 15RM during the exercises front raise, reverse flyes, shrugs, and lateral raise. For the majority of exercises, nEMG activity was high (>60% of maximal isometric contractions). From the first to the last repetition of each set nEMG—averaged for all muscles—increased 10. 0 ± 0.4% (p < 0.05) and MPF decreased −7.7 ± 0.5 Hz (p < 0.05). By contrast, nEMG activity and MPF were unchanged from the first to the third set (averaged for all muscles: 38.1 ± 23.6 vs. 47.6 ± 28.8% and 88.4 ± 21.3 vs. 82.1 ± 18.1 Hz, respectively). In conclusion, during a shoulder resistance training bout in novice individuals using 15RM loading muscle activity of the upper, medial, and lower trapezius, the medial deltoid, infraspinatus, and serratus anterior increased, and MPF decreased within each set—indicating momentary neuromuscular fatigue. By contrast, no such change was observed between the 3 sets. This indicates that momentary neuromuscular fatigue in shoulder resistance training is induced more efficiently within a set than between sets.

Keywords: electromyography, power spectrum, strength training

Introduction

Understanding the physiological mechanisms underlying training-induced gains in strength, muscle mass, and power is imperative for designing resistance training programs. The literature predominantly recommends resistance training intensities of 60% of 1 repetition maximum for novice individuals and occasionally failure training for effectively increasing muscle strength and mass (15–19,22,30). The fatigue associated with sets of resistance training stimulates cascades of anabolic signaling, and performing multiple sets may therefore be superior to single sets for increasing muscle strength (25,29). However, in novice individuals, a single set to failure can also induce significant gains in muscle strength (6,29).

Electromyography (EMG) provides valuable information on temporal and spatial muscle activation patterns during resistance training and physical rehabilitation exercises (3,4). Shifts in the EMG amplitude and power spectral analysis provide indices of fatigue (14). Fatiguing contractions increase the recruitment of additional high-threshold motor units to preserve the desired force level (20). Also, the synchronization of the motor units occurs during fatiguing contractions shifting the median power frequency (MPF) toward lower values (7).

Although several studies have examined neuromuscular activity during single repetitions of resistance training (1,3,8,11,31), information is lacking in regard to neuromuscular fatigue indices throughout a full resistance training bout. Thus, laboratory evaluations with EMG
during single sets of resistance exercises may not reflect the actual muscle activity during a full resistance training bout. In this study, we hypothesize that neuromuscular fatigue indices (simultaneous increase in EMG amplitude and decrease in MPF) in shoulder resistance training are developed more efficiently within a set than between sets.

The complex nature of the shoulder girdle implies that several muscles act together to provide both stability and motion (32). We have previously used the muscles surrounding the shoulder girdle to study muscle activation patterns during various types of muscle contraction (2,3,5). This study elaborates on these findings.

The purpose of this study is to evaluate the levels of EMG activity and fatigue indices during a standardized shoulder resistance training bout, consisting of 4 exercises with 3 sets of 15 repetitions maximum (RM).

**Materials and Methods**

Experimental Approach to the Problem

To evaluate muscle activity and fatigue indices with electromyography during a standardized shoulder resistance training bout, consisting of 4 exercises with 3 sets of 15RM, interspersed with an approximately 1-minute break between sets. For each individual muscle, the muscle activity of each of the dynamic muscle contraction was normalized to maximal isometric contractions (MVCs). All testing was conducted in October 2009.

**Subjects**

The study was performed in Copenhagen, Denmark. A group of 12 untrained (no regular training background for 2 years) women (44.9 ± 9.7 years; 166.5 ± 5.4 cm, 66.1 ± 9.3 kg) with sedentary jobs were recruited on a voluntary basis for the study. Exclusion criteria were subacromial impingement syndrome, disc prolapse, hypertension above 160/100 mm Hg, or other serious chronic diseases. None of the recruited participants met these exclusion criteria.

The participants were asked to consume a small meal with plenty of liquid 2 hours before testing. Further, the participants were asked not to perform other physical exercises on the day of testing and on the day before testing. All the participants were tested between 10 AM and 2 PM on weekdays.

All the 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 (H-3-2010-062).

**Maximal Voluntary Isometric Contraction**

Before the exercise bout, 7 MVCs were recorded to measure maximal muscle activation.

**Front Raise Maximal Isometric Contractions**

The arm is raised to 90° shoulder flexion and 90° internal rotation. The elbows are slightly flexed (5°) while the...
subject is pushing isometric upward against an external force to ensure maximal upper trapezius and infraspinatus activation.

**Shrugs Maximal Isometric Contractions.** The subject is standing on a rope with handles. The handles are placed in the hands and adjusted so that the subject stands with straight legs and fully erect back while the shoulders are lifted isometric upward to ensure maximal trapezius activation.

**Lateral Raise Maximal Isometric Contractions.** The arms are abducted to the horizontal position. The humerus is slightly flexed (30°) compared with the sagittal plane while the elbows are kept in a static, slightly flexed position (5°). The arms are lifted isometric upward against an external force to ensure maximal upper trapezius and medial deltoid activation.

**Reverse Flys Maximal Isometric Contractions.** The participant is sitting on a chair with the chest at a 45° angle from the horizontal with the arms pointing toward the floor. The arms are raised until the upper arms are horizontal, while the elbows were in a static, slightly flexed position (5°). The subject pushes upward against an external force to ensure maximal medial trapezius activation.

**Infraspinatus Maximal Isometric Contraction.** The subject is sitting fully erect. The arms are close to the body with a 90°
Elbow flexion. An external rotation in the shoulder joint is now performed against an external force to ensure maximal infraspinatus activation (23).

**Serratus Anterior Maximal Isometric Contractions.** The subject starts from a push-up position on the hands and feet or knees, bracing the abdominals to keep the torso rigid. The subject pushes the body upward against an external force to ensure a maximal serratus anterior activation (10).

**Trapezius Ascendens Maximal Isometric Contractions.** The subject lies flat on the chest with 1 arm straight above the head. The arm is now lifted upward against an external force to ensure maximal trapezius activation (24).

Two isometric MVCs were performed for each muscle, and the trial with the highest EMG was used for the subsequent analyses. The subjects were instructed to gradually increase muscle contraction force toward maximum over a period of 2 seconds, sustain the MVC for 3 seconds, and then slowly release the force again. Verbal encouragement was given during all the trials.

**Exercise Description**
The subjects were familiarized with the exercises, and 15RM was determined on a separate day before testing.

All the exercises were performed in a controlled manner, that is, lifting and lowering without a sudden jerk or...
acceleration, for 15 consecutive repetitions. The participants performed exercises in a rotating manner to optimally increase training load (29). The order of exercises was randomized for each subject, and each set of exercise was initiated every 1.5 minutes. The training session started by warming up for 10 repetitions with loadings of 50% of 1RM for each respective exercise. Four common neck-shoulder exercises were chosen: (a) front raise, (b) reverse flyes, (c) shrugs, and (d) lateral raise. These exercises are described below:

The front raise (Figure 1A) was performed as follows: From a neutral starting position, the participant raises 1 arm at a time to 90° shoulder flexion and 90° internal rotation. The elbows are slightly flexed (−5°) during the entire range of motion.

The reverse flyes (Figure 1B) were performed as follows: The participant sits on a chair with the chest at a 45° angle from the horizontal with the arms pointing toward the floor. The dumbbells are raised until the upper arms are horizontal, while the elbows were in a static, slightly flexed position (5°) during the entire range of motion.

The shrugs (Figure 1C) were performed as follows: The participant is standing upright while holding the dumbbells to the side and then elevates the shoulders while focusing on contracting the upper trapezius muscle.

The lateral raise (Figure 1D) was performed as follows: The participant stands upright while holding the dumbbells to the side and then abducts the shoulder joints until the upper arms are horizontal. The humerus is slightly flexed (30°) compared with the sagittal plane while the elbows are kept in a static, slightly flexed position (5°) during the entire range of motion.

Electromyographic Signal Sampling

The EMG signals were recorded from the midportion of the upper trapezius, medial trapezius, lower trapezius, infraspinatus, medial deltoid, and serratus anterior muscles. A bipolar surface EMG configuration (Neuroline 720 01-K, Medicotest A/S, Ølstykke, Denmark) 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, Meditec, Italy) to effectively lower the impedance to <10 kΩ. Electrode placement followed the SENIAM recommendations (www.seniam.org). 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 10–500 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, National Instruments, Austin, TX, USA) and recorded on a computer via a laboratory interface (CED 1401, Spike2 software, Cambridge Electronic Devices, Cambridge, United Kingdom).

Electromyographic Signal Processing

During later off-line analysis, all EMG signals were digitally highpass filtered using a fourth-order zerolag Butterworth filter (33) with a 5-Hz cutoff frequency and subsequently smoothed by a symmetrical moving root-mean-square (RMS) filter with a 500-millisecond time constant using custom made MatLab (Mathworks, Natick, MA, USA) programs.

The start (START) and end point (END) of each muscle contraction was located by the following Matlab routine: (a) locate the EMG peaks (MAX) separated by 1,000 milliseconds, (b) locate the minimum EMG (MIN) before and between each MAX. START is now located as the first index (searching from MIN) >5% × (MAX, − MIN) + MIN, and END as the first index (searching from MAX) < 5% × (MAX, − MIN, + 1) + MIN, + 1.

For each individual muscle, peak RMS EMG of each of the dynamic muscle contraction was normalized to the maximal RMS EMG obtained during the isometric MVCs. Further, the power spectral density of the EMG signals was calculated as the MPF for each muscle contraction. High

| Table 1. Average muscle activation (normalized EMG amplitude; percentage of MVC EMG) for the upper trapezius, medial trapezius, lower trapezius, infraspinatus, medial deltoid, and serratus anterior muscles during 4 different shoulder exercises.*†‡§¶||
|---|---|---|---|---|---|---|
| nEMG | Upper trapezius | Medial trapezius | Lower trapezius | Infraspinatus | Medial deltoid | Serratus anterior |
| Front raise | 55 (21) | 32 (11) | 52 (11) | 71 (27)§ || 53 (13) || 42 (19) ||
| Reverse flyes | 60 (23) | 71 (20)§ | 57 (16) | 63 (16) || 61 (15) || 7 (7) |
| Shrugs | 69 (26)§¶ | 30 (9) | 12 (7) | 27 (11) | 12 (8) | 9 (6) |
| Lateral raise | 63 (23)¶ | 56 (18)¶ | 54 (13)¶ | 56 (18) || 69 (11) || 41 (16) ||

*EMG = electromyographic activity; MVC = maximal isometric contractions.
†Data represents mean ± SD.
‡p < 0.01: higher than shrugs.
§p < 0.01: higher than lateral raise.
¶p < 0.01: higher than reverse flyes.
†p < 0.01: higher than front raise.
levels of muscles activation were defined in this study as normalized EMG ≥60% (3,29).

Using the present procedure of surface EMG from the shoulder muscles during evaluation of strength exercises, we have previously reported ICCs ≥0.94 for the test-retest reliability of normalized EMG between sets on the same testing day (3).

**Perceived Exertion**
Using the Borg CR10 scale, the participants rated perceived exertion immediately after the full resistance training bout (9). An increase in perceived exertion, as a function of relative load, is found to show a strong linear trend (28). The meaning of the scale was carefully explained to each individual before testing.

**Statistical Analyses**
All statistical analyses were performed in SAS version 9 (SAS Institute, Cary, NC, USA). A repeated measures analysis of variance design was used with normalized EMG as the dependent variable and muscle and repetitions as the independent variables. Further, we included a muscle by repetition interaction. Using the present procedure of surface EMG from the shoulder muscles during evaluation of strength exercises, we have previously reported ICCs ≥0.94 for the test-retest reliability of normalized EMG between sets on the same testing day (3). An alpha level of 5% was accepted as statistically significant, and all values are reported as mean ± SE unless otherwise stated.

**RESULTS**

**Training Load**
The 15RM loads for the resistance training exercises were (each hand): shrugs = 11.2 ± 2.4 kg, front raise = 3.3 ± 0.6 kg, lateral raise = 3.0 ± 0.6 kg, and reverse flyes = 1.8 ± 0.6 kg.

**Inset Differences**
The normalized electromyographic (nEMG) activity obtained for all the muscles and exercises was significantly lower (ρ < 0.001) during the first repetitions (average for the muscles 38.1 ± 23.6%) compared with the last repetitions within each set (average for the muscles 47.6 ± 28.8%) (Figure 2). Similarly, for all muscles and exercises, the MPF was higher (ρ < 0.001–0.02) during the first repetitions of each exercise (88.4 ± 21.3 Hz) compared with the last repetitions of each set (82.1 ± 18.1 Hz) (Figure 3).

**Between-Exercise Differences**
Table 1 presents between-exercise differences in nEMG. For example, the nEMG activity of the upper trapezius was statistically higher during shrugs (69 ± 26%) compared with front raise (55 ± 21%, ρ < 0.001), reverse flyes (60 ± 23%, ρ < 0.001), and lateral raise (63 ± 22%, ρ < 0.01).

Table 2 presents between-exercise differences in MPF. For example, the medial trapezius demonstrated significantly higher median power frequencies for lateral raise (98 ± 17 Hz) compared with shrugs (80 ± 10 Hz, ρ < 0.001) and reverse flyes (89 ± 10 Hz, ρ < 0.001), while the front raise (94 ± 12 Hz) was higher than shrugs (80 ± 10 Hz, ρ < 0.001).

**Perceived Exertion (Borg CR10 Scale)**
The perceived exertion was 6.3 ± 2.4 after the resistance training bout.

**DISCUSSION**
In our study, within sets, we observed a simultaneous increase in nEMG and decrease in MPF for all the muscles and exercises. Thus, momentary muscle fatigue occurred within but not between the sets of a shoulder resistance training bout. By contrast, these parameters remained unchanged between sets—that is, from the first to the third set. In addition,
As previously reported by Andersen et al., high levels of upper trapezius muscle activation were observed during various shoulder resistance training exercises (shrugs, 1-arm rows, upright rows, lateral raise, and reverse flyes). Accordingly, in this study, all 4 exercises, front raise, reverse flyes, shrugs, and lateral raise induced high levels of EMG in the upper trapezius. Additionally, except for serratus anterior, all the investigated muscles demonstrated a high level of muscle activity (>60% of maximal EMG) within 1 or several of the 4 exercises. The level of muscle activity was somewhat exercise specific; the upper trapezius demonstrated the highest nEMG activity during shrugs, whereas the middle and lower trapezius muscles were activated more by the reverse flyes, whereas infraspinatus nEMG activity was the highest during the front raise, and finally the deltoid muscle was activated most during the lateral raise. Consequently, when training for increased shoulder stability and strength, the 4 exercises provide good all-round shoulder strength training.

The fact that the EMG measurements were performed on untrained participants limits the generalization of our findings to novice trainees. However, Izquierdo et al. (21) observed that after short-term heavy resistance training (7 weeks), when the relative intensity of a fatiguing dynamic protocol was kept the same, the rate of loss in MVC and power was higher than before training, but the neural activity (relative amplitude and MPF) was similar to pretraining values.

In conclusion, during a full resistance training bout, indices of fatigue were observed within each set, that is, simultaneous increase in nEMG activity and decrease in MPF for all muscles and exercises. By contrast, these parameters remained stable from the first to the third set of exercise. Thus, momentary neuromuscular fatigue is more effectively induced within a set than between sets.

**Practical Applications**

From a practical perspective, our results suggest that a single set of resistance training is sufficient to achieve high levels of momentary fatigue, that is, no accumulating levels of neuromuscular fatigue were observed during multiple set training with an approximately 1-minute break between sets. These results are important to bear in mind when the training goal is to fatigue the muscle.

The effectiveness of the reverse flye exercise may be underappreciated in many strength training settings. Consequently, if time is limited, the reverse flyes seem to be the foremost exercise to reach an overall high level of muscle activity within the selected muscles (except for serratus anterior). Moreover, regarding practical relevance, the external load was the lowest during the reverse flyes, lateral raise, and front raise exercise (reverse flyes: 1.8 kg; lateral raise: 3.0 kg; front raise: 3.3 kg vs. shrugs: 11.2 kg). Hence, the reverse flyes, lateral raise, and front raise may be appropriate
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exercises for people with low back, hip, and hand grip strength, which can be a potential problem during the heavier loads of the shrugs exercise.

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