Background: Resistance training to failure is an advanced method often used by healthy individuals. Little is known about this type of training in individuals with musculoskeletal pain.

Purpose: This study investigates the effect of 10 weeks’ elastic resistance training on neck and shoulder muscle activity during a single set to failure.

Study design: This was an observational cohort study.

Methods: Sixteen untrained, female office workers with chronic neck and shoulder pain performed 10 weeks of elastic resistance exercise as a single set of lateral raise to failure during workdays. Electromyography (EMG) amplitude and median power frequency (MPF) from the splenius and the upper trapezius muscles were analyzed.

Results: EMG amplitude increased and MPF decreased linearly from the first to the last repetition during the set, before and after the 10 weeks of training. For the first few repetitions of exercise, muscle activity was higher after 10 weeks than before the intervention (91% vs. 74%, $P = 0.03$). However, during the last repetitions, similar high levels of EMG amplitude were noted both before and after the 10 weeks (129% vs. 127%, $P = 0.81$). The MPF before and after the training intervention was 79 and 77 Hz ($P = 0.69$), respectively, during the first repetitions, and 66 and 69 Hz ($P = 0.62$) during the last repetitions of exercise. The increase in EMG and decrease in MPF – which were similar before and after 10 weeks – are good indicators of acute muscle fatigue.

Conclusion: The results indicate that untrained women with neck-shoulder pain are capable of training to failure, and concur with previous results showing rapid benefits in terms of muscle strength and pain reductions from this type of training.

Keywords: Strength training; workplace training; trapezius myalgia; EMG; fatigue

Key Points: Untrained women with neck and shoulder pain were able to exercise to muscular failure, using elastic bands without direct supervision in the workplace setting.
INTRODUCTION

The positive effects of regular physical activity on both physical and mental health are well established.\(^1\)\(^-\)\(^^4\) When specifically aiming to reduce musculoskeletal pain in the neck and shoulder, targeted resistance training has proven effective.\(^5\)\(^-\)\(^^8\)

To induce physiological changes, exercise intensity is an essential component of resistance training.\(^9\) Performing resistance training to a level of exhaustion, that is, until one is unable to continue performing the exercise with the complete range of movement because of fatigue, is known as training to failure.\(^10\) Exercise-induced effects of training to failure include an increased activation of the motor units and a greater mechanical stress on the musculature, both of which are related to enhanced gene expression and muscular damage with subsequent muscle repair.\(^11\)

Most existing knowledge on the physiological effects of training to failure is based on individuals with a certain training experience.\(^12\)-\(^14\) Thus, whether the muscular and nervous system adaptations of training to failure are applicable even to untrained individuals is not well elucidated. Furthermore, there is a lack of certainty on whether untrained individuals with musculoskeletal pain are capable of performing training to failure, which requires intense physical effort.

Laboratory studies have shown that untrained individuals can reach fatigue during resistance training by using either dumbbells or elastic resistance bands.\(^15\),\(^16\) However, these studies have been conducted in a laboratory setting, under supervision and with verbal encouragement; therefore, the results may not apply to everyday setting. Whether the intense physical demands of training to failure can be fulfilled by untrained individuals outside the laboratory, without supervision and encouragement from an instructor, is unknown.

PURPOSE/HYPOTHESIS

The aim of this study was to evaluate the effects of 10 weeks’ resistance training, performed at the workplace, on the dominant neck and shoulder muscle activity during a single set to failure of lateral raise in untrained female office workers experiencing pain in the neck and shoulder. We hypothesized that muscle activity would be higher after 10 weeks of training than that before the exercise. The main reasons for the expected increase in muscle activity are (i) familiarization with the exercise,\(^17\) (ii) neural adaptations that enable the use of greater relative resistance at the end of the training period,\(^18\) and (iii) reduced neck-shoulder pain and thereby reduced fear-avoidance.\(^19\),\(^20\)

METHODS

Study Design and Participants

This study was a subanalysis performed on data nested in a larger randomized controlled trial performed in Copenhagen, Denmark, from September to December 2009. The main results of the randomized controlled trial with 198 participants are reported elsewhere.\(^21\) For the present study, electromyography (EMG) measurements in a subsample were used to assess the effects of a 10-week resistance training intervention on the activity of trapezius and splenius muscles during a single set of lateral raise to failure. We have previously reported EMG findings during daily work tasks (computer work, office work) in this population.\(^22\)

The participants of this study were 16 untrained, female, full-time office workers experiencing chronic neck and shoulder pain. They worked five days per week and their work mostly involved the use of computers (Table 1). The complete list of exclusion criteria is reported elsewhere,\(^21\) and included fibromyalgia, rheumatoid arthritis, chronic disease, and performing more than two hours of vigorous physical activity per week.

All participants were informed about the purpose and content of the study, and they provided their written informed consent before participating in the study, which conformed to The Declaration of Helsinki and was approved by the Local Ethical Committee of Copenhagen and Frederiksberg (HC2008103). The study is registered as ISRCTN60264809 in Current Controlled Trials.

Participants performed one training session daily during their working hours. The session consisted of a single set of shoulder abduction (lateral raise) by using elastic resistance tubing (TheraBand®, Performance Health, Akron, Ohio). The elastic resistance tubing was color coded in red, green, and blue. According to the manufacturer, the resistance at 100% elongation corresponds to 3.7 pounds (red), 4.6 pounds (green), and 5.8 pounds (blue).\(^21\) Lateral raise is a validated exercise that effectively activates the neck and shoulder muscles.\(^15\),\(^23\) The exercise was done in the scapular plane at a level of 90° of shoulder abduction and 30° of horizontal shoulder adduction and performed with as many consecutive repetitions as possible until muscular fatigue. The first session served as the baseline measurement. The participants were encouraged to beat their previous record. They were instructed to use only the red elastic tubing as resistance and perform as many repetitions as they could during the first two weeks; when they were able to perform 22 repetitions before reaching failure, then they could progress to higher levels of resistance, namely, green, blue, and then red combined with green.
After each training session, training activities were recorded in a log to allow for a gradual progression in repetitions and resistance. The study details were explained to all participants orally and through a written manual. Adherence was defined as the number of completed training sessions expressed as a percentage of the total number of training sessions throughout the intervention period. The intervention was identical for the subset as for the entire group; thus, the only intervention performed was the exercise with the elastic tubing.

**Electromyographic Data Acquisition**

The EMG signals were recorded from both trapezius and splenius muscles of the dominant side by using a bipolar surface EMG configuration (Ambu Blue Sensor N, N-00-S; Ambu A/S, Ballerup, Denmark) with an inter-electrode distance of 2 cm. Before applying the electrode pairs, placement sites were abraded to lower the impedance level to less than 10 k\(\Omega\). Both electrode pairs were placed in accordance with the SENIAM guidelines (http://www.seniam.org).

All electrode pairs were connected to a wireless probe (Velamed Medizintechnik GmbH; Cologne, Germany) placed to the skin. The probe both served as the reference electrode and pre-amplified the EMG signal (gain 400) before transmitting the data in real-time into a 16-channel 16-bit PC-interface receiver (Noraxon Telemyo DTS Telemetry; Noraxon, Arizona, USA). All data were collected using a sample rate of 1500 Hz within a bandwidth of 10-500 Hz.

The EMG recordings were conducted at the workplace as the participants performed their regular work. Although the EMG recordings covered the whole workday, this study was focused on the daily training session, which consisted of one set to failure of elastic resistance training performed mid-day by the participants without the involvement of the researchers. In addition to the daily training session, the participants also performed both a relaxation measurement and an isometric maximal voluntary contraction (MVC), which were subsequently used to normalize the EMG signal.

The relaxation measurement was conducted at the beginning of the workday. The participants were instructed to perform 30 s of seated rest with their eyes closed, arms fully supported, and shoulder and neck muscles completely relaxed. The maximal EMG measurement was conducted just before the end of the workday to avoid maximal contraction from being influenced by other measurements of this study. In the seated position, the participants were instructed to hold their arms straight and horizontal in 90-degree abduction, and keep the hands relaxed and palms faced downward. In this position, the participants were told to lift their arms as forcefully as possible against resistance offered by the instructor. Isometric MVCs were performed 2 times for a period of 5 s, each separated by 30 s of rest.

**Electromyographic Data Processing**

The data processing was performed in MatLab (MathWorks, version 7.5.0 342, R2007b; Sherborn, Massachusetts, USA). Initially, the training session

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**Table 1. Baseline characteristics**

| Participants \(n = 16\), mean ± SD |     |
|-------------------------------------|-----|
| Age (years)                         | 41.7 ± 10.8 |
| Height (cm)                         | 168.8 ± 6.7 |
| Weight (kg)                         | 66.5 ± 9.1  |
| Body mass index (kg/m\(^2\))        | 23.3 ± 2.9  |
| Mean pain intensity during previous 3 weeks (Scale 0-10) | 3.44 ± 1.40 |
| Systolic blood pressure (mm Hg)     | 125.3 ± 12.3 |
| Diastolic blood pressure (mm Hg)    | 85.5 ± 8.4  |
| Computer use (% work time)          | 98.4 ± 6.3  |
| Weekly working time (hours)         | 38.2 ± 3    |
| Duration of office work (years)     | 10.3 ± 8    |
was divided into a number of periods, each containing one repetition. These periods were subsequently visually controlled and adjusted if incorrect. To normalize the EMG signals, the maximal root mean square (RMS) during the isometric MVC was determined using a moving window of 1500 data points (i.e. 1 s) and a movement duration of 100 ms per window. Hereafter, the resting EMG amplitude was determined by identifying the lowest RMS using a moving window of 7500 data points (i.e. 5 s) and a movement duration of 100 ms during the relaxation measurement. The lowest RMS value obtained during the relaxation measurement was quadratically subtracted from all other EMG signals to remove background noise. Furthermore, the RMS for each repetition during the training sessions was determined, using the same procedure as that for the MVC EMG amplitude, and subsequently normalized to the MVC EMG. If the average EMG amplitude during the first three repetitions of the set – i.e., in the non-fatigued state – exceeded the MVC EMG (i.e., 100%), then the EMG amplitude of each repetition of the set was downscaled so that the average of the first three repetitions was equal to 100%. This was done to avoid unrealistically high EMG values during the set and thus avoid over-interpretation of the training intensity. For the RMS plots of relaxation measurement, the MVC and all repetitions were controlled for 50 Hz interference, unilateral spikes, and abnormalities in the EMG signal by visual inspection. Finally, the median power frequency (MPF) of the EMG signals was determined by performing a spectral analysis of the median value for each repetition during the daily training session. This calculation was based on Welch’s method, using Hamming window intervals with a 50% overlap, with a calculation of fast Fourier transformation for each interval.

### Statistical Methods

All statistical analyses were performed in SAS version 9 (SAS version 9; SAS Institute, Cary, NC). A repeated measures analysis of variance (RM-ANOVA) design was used, with normalized EMG as the dependent variable and Repetition and Test Round as the independent variables. Further, Repetition by Test Round interaction was included. Before performing the statistical analysis, muscle activities of the trapezius and splenius muscles for each repetition were averaged as they appeared closely related, thereby giving an estimate of the total activation of the neck and shoulder musculature during each repetition. Further, the variable Repetition was divided into 0-10%, 10-20%, ..., 90-100% of the total number of repetitions for each subject to be able to compare across subjects and test rounds. 

### Results

#### Muscle Activation

When testing main and interaction effects for the normalized EMG, a significant effect was found for Repetition (\(P < 0.001\)), Test Round (\(P < 0.01\)), and Repetition by Test Round interaction (\(P < 0.001\)). Figure 2 shows that muscle activity increased linearly during the repetitions to failure. During the initial repetitions of the set – i.e., in the non-fatigued state – muscle activity was higher after 10 weeks of training than before (91% vs. 74%, \(P = 0.03\)). However, during the last repetitions – i.e., in the fatigued state – similar high levels of EMG amplitude were achieved before and after the 10 weeks of training (129% vs. 127%, \(P = 0.81\)).

#### Median Power Frequency

When testing main and interaction effects for the MPF, a significant effect was found for Repetition (\(P < 0.001\)). Figure 3 shows that MPF decreased in a linear fashion from the first to the last repetition. We also found a significant Repetition by Test Round interaction (\(P < 0.05\)), but this seemed of minor practical relevance as the MPF before and after 10 weeks was 79 and 77 Hz (\(P = 0.69\)), respectively, during the first repetitions, and 66 and 69 Hz (\(P = 0.62\)), respectively, during the last repetitions, indicating muscle fatigue in response to the set to failure both before and after the training period.

### Discussion

The main finding of this study is that untrained women with neck and shoulder pain are capable of training to failure despite their pain. This finding explains previous results showing rapid benefits in terms of muscle strength and pain reductions from this type of training. The current study was performed in a group of untrained individuals. We hypothesized that the participants would show less level of muscle...
activity before than after the 10 weeks of training, because they were not familiarized to performing vigorous physical activity. However, the results show a similar level of muscle activity during the past repetitions of the set failure both before and after the intervention period. This suggests that untrained individuals are able to perform training to failure without a period of familiarization, which is in contrast to the current resistance training guidelines. A possible explanation for this discrepancy is that the “lateral raise” exercise chosen in this study was so technically simple that the participants were able to perform it with minimal instructions.

After the 10-week training period, the EMG amplitude for the first repetition of the daily training set to failure was significantly increased when compared with that before the training period. This change in EMG amplitude is due to an increased relative resistance as a result of the progressive training regime of the study. The participants were able to increase the elastic resistance after the intervention period as a consequence of a range of possible neural and muscular adaptations, which may include a greater number of muscle fibers being recruited, an enhanced firing rate, and an increased synchronization of the motor units. The increase in EMG amplitude when performing the initial repetition after the training period is somewhat expected because of the possible neural and muscular alterations and higher resistance of the elastic tubing. However, the EMG amplitude reached similar levels in the fatigued state, i.e., during the last repetitions. Thus, going to failure regardless of the resistance – within the limits of relative resistance used in the present study – induced similar high levels of EMG amplitude.

The MPF decreased throughout the set to failure, both before and after 10 weeks’ training. This indicates, together with the EMG amplitude changes described above, similar development of local muscular fatigue. The decrease in MPF is likely a result of increased synchronization of motor unit firing as typically seen in the fatigued state of muscle contraction. The present results of increased EMG amplitude and decreased MPF throughout the set to failure are similar to those reported in previous studies. These studies were performed as classical laboratory studies and therefore conducted in a controlled

\[ \text{Figure 1. Progression in average resistance, presented on the primary vertical axis, combined with the average number of repetitions per training session, presented on the secondary vertical axis. A resistance of 1, 2, 3, or 4 is equal to the use of an elastic resistance tubing colored red, green, blue, or red plus green, respectively.} \]
Figure 2. Normalized EMG during repetitions to failure of lateral raise before and after 10 weeks of training. *Significantly higher muscle activity after the training period ($P < 0.05$).

Figure 3. Median power frequency (MPF) during repetitions to failure of lateral raise before and after 10 weeks of training.
environment, which enabled the researchers the opportunity to constantly optimize the testing conditions, secure safe execution of resistance training exercises, and give verbal encouragement throughout the training sessions. In contrast, the current study was performed in a workplace setting and was subject to the daily working routines of the workplace. Consequently, the participants conducted all training activities without supervision of any kind.

The present findings show that it is possible to perform training to failure outside the laboratory without being provided with constant external supervision and encouragement. Individuals who suffer from chronic musculoskeletal pain are often reluctant to perform high-intensity training as a result of fear-avoidance. However, in the present study, the level of muscle activity at the point of failure was unaffected by the pain intensity at the start of the training intervention. A possible explanation for the results could be that this specific job group may not be particularly affected by fear-avoidance during the present exercise because it was performed in a slow and controlled manner.

LIMITATIONS

Our study has both strengths and limitations. Using surface EMG to determine muscle activity has some inherent weaknesses. The predominant factors affecting the EMG signals are the electrode placement, and the distance between the electrodes. In addition, the EMG signals are sensitive to crosstalk from the adjacent musculature. However, these issues are minimized by using the recommended procedures for surface EMG, and previous research has proven that the EMG signals from trapezius and splenius muscles can be separated. Furthermore, the reliability of the EMG measurements is increased when normalizing the EMG signals according to the maximal EMG amplitude obtained during the MVC.

Additionally, it is not possible to generalize the findings on the dominant neck and shoulder muscles from this study to all human muscles. The neck and shoulder muscles have a general muscle fiber composition, which primarily consists of Type I fibers. Because Type I fibers are characterized as having slower twitch and high endurance when compared with the Type II fibers, it is possible that muscles with a more pronounced expression of Type II fibers would have a different reaction to training to failure.

CONCLUSION

In conclusion, untrained women with neck and shoulder pain are capable of performing resistance training to failure in spite of pain and without having a prior familiarization period. This may explain previous results showing rapid benefits in terms of muscle strength and pain reductions from this type of training. Further, untrained individuals are capable of performing and completing training to failure in a workplace setting without the need of supervision after the initial instruction on how to perform the exercise.

CLINICAL RELEVANCE

Data from the present study show that untrained individuals experiencing frequent musculoskeletal pain are able to perform simple, non-complex resistance training to failure without prior familiarization. In addition, the results indicate that untrained individuals are capable of completing a training period in a workplace setting with minimal instructions. This gives the coach or trainer a better opportunity to be more focused and spend time more effectively when attending training sessions and supervising primarily the untrained individuals. Importantly, training in a workplace setting does not pose a problem with respect to reaching near maximal intensities and does not require machines or heavy equipment as the exercise was performed using simple elastic resistance.

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