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# Changes in EMG activity of the prime movers during 10 sets of the flat bench press performed to concentric failure

**Authors' Contribution:**
**A** Study Design
**B** Data Collection
**C** Statistical Analysis
**D** Data Interpretation
**E** Manuscript Preparation
**F** Literature Search
**G** Funds Collection

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## abstract

**Background:** The bench press (BP) is a complex exercise of the upper body in which great external loads requiring high neuromuscular activity can be lifted. Electromyography (EMG) is a study of the muscle function through the inquiry of the electrical signal the muscles emanate. The aim of the present study was to analyse changes in EMG activity of the prime movers during 10 sets of the flat bench press.

**Material and methods:** Ten male athletes representing different sport disciplines, experienced in resistance training took part in the study.

**Results:** In the first set, all of the tested muscles increased their tension from the first 3 repetitions to the last 3 repetitions. The tension of these muscles increased in successive repetitions and reached significantly greater values in the last repetitions of the set. In the 10th final set of the BP exercise protocol the athletes performed only 8-9 repetitions, and the activity of all studied muscles decreased significantly from the first 3 to the last 3 repetitions of the set.

**Conclusions:** It seems that peripheral fatigue limits the number of repetitions in the first set of the BP, while central fatigue accumulates with each set, causing a very significant drop in EMG activity and the load lifted in the 10th, last set of the exercise protocol.

**Key words:** bench press, EMG activity, muscular fatigue, resistance exercise.

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## INTRODUCTION

The Flat Bench Press (FBP) is one of the most popular strength exercises performed by athletes of both individual and team sports [1]. The BP is a complex exercise of the upper body in which great external loads requiring high neuromuscular activity can be lifted. The bench press exercise plays an important role in recreational and professional training, including power lifting, in which this exercise is a competitive event [2]. BP performance is significantly influenced by the strength and power of several muscle groups and by proper technical execution of the movement [3]. This exercise is used in forming muscle strength and muscular power, hypertrophy and anaerobic endurance. Depending on anthropometric variables and movement technique muscular activity patterns vary during the BP, yet most research confirms that three muscle groups are involved as prime movers in this exercise: *pectoralis major* (PM), *anterior deltoid* (AD) and *triceps brachii* (TB) [4]. The strategies set by the central nervous system to provide the performance required by the exercise are held constant throughout the exercise, but the tonic aspects of the Central drive are increased so as to adapt to the progressive occurrence of the neuromuscular fatigue. Changes in tonic control as a result of muscular weakness and fatigue can cause changes in movement techniques. These changes may be related to a limited ability to control mechanical loads and mechanical energy transmission to joints and passive structures [5].

Electromyography (EMG) is a study of the muscle function through an inquiry of the electrical signal the muscles emanate. It is concerned with the development, recording and analysis of myoelectric signals which are formed by physiological variations in the state of muscle fibre membranes [6]. Data collected from EMG analysis inform us if the muscle is active, if it is more or less active (in comparisons), when it is on/off, how much it is active and whether the muscle fatigues. EMG data addresses how much work or effort a particular muscle needs to share in a certain exercise or task. This is important in order to understand the effect of resistance exercises and reveal their character of being low, submaximal or maximal in demand. When targeting muscular hypertrophy or local strength endurance, fatigue plays a significant role in most adaptive changes. Training-induced short-term fatigue is a preliminary condition for muscle growth and an improvement in anaerobic endurance. The study of local muscle fatigue effects has two important applications. First, it can be used to identify weak muscles. Second, it can be used to evaluate the efficiency of strength training exercises [6]. Changes in performance in relation to the abovementioned factors have been carefully investigated in humans in response to different types of exercise [7]. Thus, declines in performance during resistance exercise are attributed to CNS, which integrates input from various body parts and is known as central fatigue. In the case of resistance training, central fatigue is poorly investigated and recognised [8].

Analysis of muscular activity during the BP has been described extensively in the literature [9, 10]. However, few, well-controlled studies have examined the changes in EMG activity of the prime movers during multiple sets of the flat bench press performed to concentric failure. Several studies have shown that rest intervals between sets have a significant effect on changes in muscular activity and the total volume of weight lifted in a training session [11, 12, 13]. It thus seems absolutely necessary to control this variable (rest interval) during such experiments. Therefore, the aim of the present study was to analyse changes in EMG activity of the prime movers during 10 sets of the flat bench press performed to concentric failure with a load of 60% 1RM and 4 min rest intervals.

## MATERIAL AND METHODS

### PARTICIPANTS

Ten male athletes representing different sport disciplines, experienced in resistance training took part in the study. Their average age, body mass and body height equalled respectively 32 ±4.6 years, 86.3 ±5.2 kg and 181.3 ±4.2cm. Their average 1RM equalled 112.5 kg. The participants did not perform any additional resistance exercises for 72 hours prior to testing to avoid fatigue. All the subjects were informed verbally and in writing about the procedures, possible risks and benefits of the tests, and they provided written consent before the commencement of the study.

The study received an approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland (NRSA 404054).

### PROCEDURES

A standardised warm-up protocol was used before the experimental exercise protocol began. The athletes performed a general warm-up (5 minutes), using a hand cycle ergometer (the heart rate of approximately 130 bpm) and several lower and upper body resistance exercises. The specific part of the warm-up consisted of three bench press sets with the load adjusted accordingly to perform 15, 10 and 5 repetitions. One week before the main experimental session took place, all of the athletes taking part in the study were evaluated for the 1 RM flat bench press. The determination was performed according to the protocol proposed by Tillar & Saeterbakken (2014). After the warm-up and 10 minutes before the start of the experimental exercise protocol, 2–3 s tests of isometric exercise were performed in order to normalize electromyographic records according to the SENIAM procedure [14]. The normalization procedure was conducted for each side of the body separately. Analysis was based on peak activity during the bench press (from both the eccentric and concentric phases). Afterwards, each study participant performed 10 sets of the flat bench press, with a load of 60% 1RM, each to voluntary concentric muscular failure with the rest intervals of 4 minutes between sets. The bench press exercise protocol was performed with an Eleiko Olympic bar and plates. A competition bench was used, and 2 experienced spotters assisted the tested subjects. Each athlete performed 10 sets of the bench press witch a load of 60% 1 RM until concentric failure. Changes in peak muscle activity (average value of 3 repetitions) for the four considered muscles (PM, AD, TBlateral and TBlong) during the eccentric and concentric phases of the flat BP were analysed during the first and the last 3 repetitions of the 1st and the 10th set. The SUM of peak muscle activities of all the studied muscles was used to create the Total Strength Activity Index (TSAI, %). This index informed about the input of particular muscles into the total muscle activity generated to overcome particular resistance.

The total volume of work was calculated for each athlete in particular sets and in the whole exercise protocol, multiplying the resistance by the number of repetitions in each set, and by the number of sets [10]. Changes in EMG activity and in the amount of lifted weight in particular sets would reflect muscular fatigue. The research was performed in the Strength & Power Laboratory at the Academy of Physical Education in Katowice, Poland.

## Electromyography

An eight-channel Noraxon TeleMyo 2400 system (Noraxon USA Inc., Scottsdale, AZ; 1500Hz) was used to record and analyse biopotentials from the muscles. The activity was recorded for four muscles: PM, AD, TBlateral and TBlong. Before placing gel-coated self-adhesive electrodes (Dri-Stick Silver circular sEMG Electrodes AE-131, NeuroDyne Medical, USA), the skin was shaved, abraded and washed with alcohol. The electrodes (11 mm contact diameter and a 2 cm centre-to-centre distance) were placed along the presumed direction of the underlying muscle fibre according to the recommendations by SENIAM [15]. The EMG signals were sampled at a rate of 1000 Hz. Signals were band pass filtered with a cut-off frequency of 8 Hz and 450 Hz, after which the root-mean-square (RMS) was calculated. Following standard procedures, all the electrodes were located on the right side of the participant, regardless of whether this was the dominant side or not. The grounding electrode was placed on the connection with the *triceps brachii* muscle. Video recording was used for identification of the beginning and completion of the movement.

## Statistical analysis

Shapiro-Wilk, Levene and Mauchly's tests were used in order to verify the normality, homogeneity and sphericity of the sample's data variances, respectively. Verifications of the differences between analysed total volumes and values of tensions of individual muscles between first 3 repetitions and last 3 repetitions in Bench Press were carried out using ANOVA with repeated measures. Effect sizes (Cohen's d) were reported for results, where appropriate. Parametric effect sizes were defined as large for $d > 0.8$, as moderate for between 0.8 and 0.5, and as small for $< 0.5$ [2, 16, 17]. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using Statistica 9.1, and Microsoft Office, and presented as means with standard deviations.

## Results

Changes in volume of the load lifted in particular sets of the bench press are presented in Figure 1.

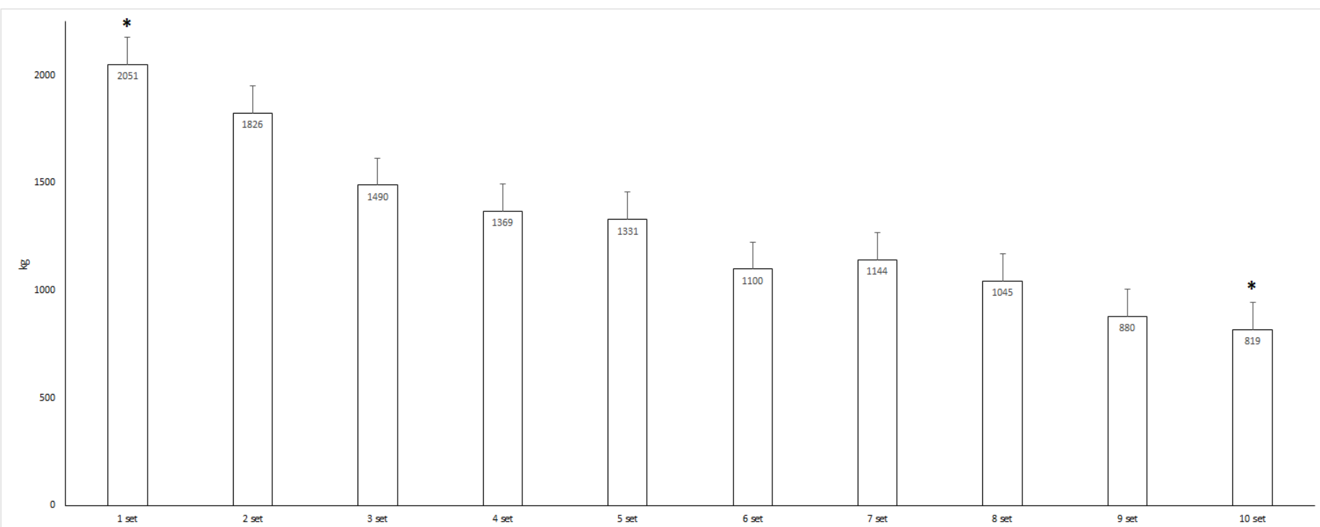


**Fig. 1.** Changes in volume of the load lifted in particular sets of the bench press exercise protocol

Table 1 presents changes in muscle activity during the BP exercise protocol between the first 3 and the last 3 repetitions in the 1st and 10th set of the flat bench press performed to concentric failure.

The repeated measures ANOVA (Table 2) for values of individual muscle tensions between the first 3 and the last 3 repetitions in the 1st set of bench press revealed statistically significant differences for *anterior deltoid* (p = 0.001; $d$ = 0,601), *pectoralis major* ($p$ = 0.002; $d$ = 0,486), long head of *triceps brachii* ($p$ = 0.002; 0,465).

The repeated measures ANOVA (Table 3) for values of individual muscle tensions between the first 3 and the last 3 repetitions in the 10th set of BP exercise protocol revealed statistically significant differences for *anterior deltoid* (p = 0.001; d = 0.618), *pectoralis major* ($p$ = 0.001; $d$ = 0.884), lateral head of *triceps brachii* (p = 0.001; d = 0.874), and long head of *triceps brachii* (p = 0.001; d = 0.587).

**Table 1.** Changes in muscle activity during the bench press exercise protocol between the first 3 and the last 3 repetitions of the 1st and 10th set of the flat BP performed to concentric failure

| Muscles | First 3 rep. | Last 3 rep. | First 3 rep. | Last 3 rep. |
|---|---|---|---|---|
| | 1st set | | 10th set | |
| Anterior deltoid | 30 | 57 | 77 | -10 |
| Pectoralis major | 18 | 30 | 97 | -80 |
| Lateral head of triceps brachii | 51 | 53 | 28 | -93 |
| Long head of triceps brachii | 13 | 27 | 41 | -15 |

**Table 2.** The analysis of variance for individual muscle tensions between the first 3 and last 3 repetitions in the bench press in the 1st set of the BP exercise protocol

| Muscles | d | p | F |
|---|---|---|---|
| Anterior deltoid | 0.601 | 0.001* | 12.124 |
| Pectoralis major | 0.486 | 0.002* | 8.241 |
| Lateral head of triceps brachii | 0.116 | 0.213 | 0.039 |
| Long head of triceps brachii | 0.465 | 0.002* | 7.141 |

** statistically significant values*

**Table 3.** The analysis of variance for individual muscle tensions between the first 3 and last 3 repetitions in the 10th set of the BP exercise protocol

| Muscles | d | p | F |
|---|---|---|---|
| Anterior deltoid | 0.618 | 0.001* | 18.534 |
| Pectoralis major | 0.884 | 0.001* | 102.701 |
| Lateral head of triceps brachii | 0.874 | 0.001* | 88.034 |
| Long head of triceps brachii | 0.587 | 0.001* | 12.678 |

** statistically significant values*

## DISCUSSION

Resistance training has been recognised as an essential component of conditioning for athletes of different sport disciplines. Depending on the prescribed variables, resistance training can increase maximal strength, hypertrophy, power or muscular endurance. These variables include exercise choice and order, load or intensity, number of sets and repetitions, and rest intervals between sets and exercises [13, 18, 19]. The abovementioned variables can be manipulated by the coach to induce specific adaptive changes necessary for particular athletes [20, 21]. There are numerous sports disciplines that require a high level of local muscular endurance. These include combat sports, swimming, rowing, speed skating and cycling. Training for the improvement of muscular endurance requires the performance of multi-set resistance exercises with a low to moderate load (30‒60% 1RM) and many repetitions (15‒40) in a single set, often to concentric or eccentric failure. During such exhaustive training procedures, athletes face fatigue. Fatigue in resistance exercises is expressed by decreased excitability and contractibility of the muscles during successive repetitions. Fatigue may involve central ‒ CNS, [22] and/or peripheral sites [23]. Peripheral fatigue appears when depletion of energy stores occurs, accumulation of by-products or impairment of muscle contractile mechanism is attained in response to resistance exercise. Changes in performance in relation to the abovementioned factors were carefully investigated in humans in response to different types of exercise, yet they cannot be fully explained by peripheral fatigue [7]. Declines in performance during exercise are also attributed to the CNS, which integrates input from various body parts and is known as central fatigue. In the case of resistance training, central fatigue is poorly investigated and recognised [8].

Muscular fatigue in resistance exercises can be studied by biochemical and physiological markers or through analyses of the level and duration of bioelectrical muscle activity [24].

When the load on muscles increases, the engagement of motor units, and the frequency of stimulation must also increase in order to reach the necessary muscle tension. During the bench press, the activity of the *pectoralis major* (PM), *anterior deltoid* (AD) and *triceps brachii* (TB) increases along with the load and the speed of movement [24]. On the other hand, when the load remains constant and numerous sets with many repetitions performed to exhaustion changes in EMG activity of the prime movers are less investigated.

In our study we attempted to evaluate changes in EMG activity of the prime movers during 10 sets of the flat bench press, each performed to concentric failure. We compared EMG activity of each muscle separately and their total activity between the first and the last 3 repetitions of the first and 10th set. Our study was unique as we tested experienced strength trained athletes and we induced extreme fatigue in the muscles through the 10 sets of the bench press performed to concentric failure. We hypothesized that different mechanisms would be involved in fatigue during the first and the last set of the BP exercise, which would be reflected in changes of EMG activity and a significant drop in the total weight lifted in particular sets.

We observed a gradual and significant decrease in the amount of repetitions and weight lifted in successive sets of the BP exercise protocol. The total value decreased almost three times from the 1st to 10th set of the exercise protocol, which indicated the presence of systematic fatigue. In the first set the athletes performed approximately 24‒25 repetitions and all of the tested muscles increased their tension from the first 3 repetitions to the last 3 repetitions. Because the applied load equalled only 60% 1RM, the muscle tension in the prime movers was rather low in the first 3 repetitions. The tension of these muscles increased in successive repetitions and reached significantly greater values in the last repetitions of the set, when the CNS had to increase its firing

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frequency in order to overcome the load under circumstances of progressive peripheral fatigue [23]. In the 10th final set of the BP exercise protocol the athletes performed only 8–9 repetitions and the muscle activity of all studied muscles decreased significantly from the first 3 to the last 3 repetitions of the set. The limited amount of repetitions performed in the last set, and the inability to increase tension in successive repetitions can be explained by fatigue of the CNS [8].

## CONCLUSIONS

The multi-set resistance exercises performed with a moderate load (60%1RM) to concentric failure may result in considerable acute fatigue of central and peripheral origin.

The reduced electrical activity in the muscles accompanied by an accumulation of blood lactate led to marked decreases in strength.

It seems that peripheral fatigue limits the number of repetitions in the first set of the BP, while central fatigue accumulates with each set, causing a very significant drop in EMG activity and load lifted in the 10th, last set of the exercise protocol.

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