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

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

abstract

Background: The bench press (BP) is a complex exercise of the upper body in which great external loads can be lifted, requiring high neuromuscular activity. Electromyography (EMG) is the study of muscle function through the inquiry of the electrical signal the muscles emanate.

Material/Methods: The aim of the present study was to analyze changes in the EMG activity of the prime movers during 10 sets of the flat bench press. 10 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 the 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 coefficient.

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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 can be lifted, requiring high neuromuscular activity. 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 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 the study of muscle function through the inquiry of the electrical signal the muscles emanate. It concerns the development, recording and analysis of myoelectric signals which are formed by physiological variations in the state of muscle fiber membranes [6]. Data collected from EMG analysis inform us if the muscle is active, if it is more or less active (in comparisons), when the muscle is on/off, how much the muscle 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 the preliminary condition for muscle growth and 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 above-mentioned factors were 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 case of resistance training, central fatigue is poorly investigated and recognized [8].

Analysis of muscular activity during the BP has been described extensively in the literature [9,10]. However, few, well controlled studies have examined 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 essential to control this variable (rest interval) during such experiments. Therefore, the aim of the present study was to analyze 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 equaled respectively 32 ±4.6 years, 86.3 ±5.2 kg. and 181.3 ±4.2cm. Their average 1RM equaled 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 provided written consent before the commencement of the study. The study received approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland (NRSA 404054).

PROCEDURES

A standardized 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 the peak activity during the bench press (both from 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 the 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% 1RM until concentric failure. Changes in the 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 analyzed during the first and the last 3 repetitions of the 1st and 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 a 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 the 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.

The athletes taking part in the study were familiarized with the procedures, possible benefits and side effects of the research, signing consent for participation before the commencement of the study. The study received approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland No. 5/2015.

Electromyography

An eight-channel Noraxon TeleMyo 2400 system (Noraxon USA Inc., Scottsdale, AZ; 1500Hz) was used for recording and analysis of 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 center-to-center distance) were placed along the presumed direction of the underlying muscle fiber 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.

Staticstical 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 the analyzed total volumes and values of tensions of individual muscles between the first 3 repetitions and the 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 $d < 0.5$ [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 the volume of the load lifted in particular sets of the bench press are presented in Figure 1. 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 ($p = 0.002$; $d = 0.486$), the long head of triceps brachii ($p = 0.002$; 0.465).

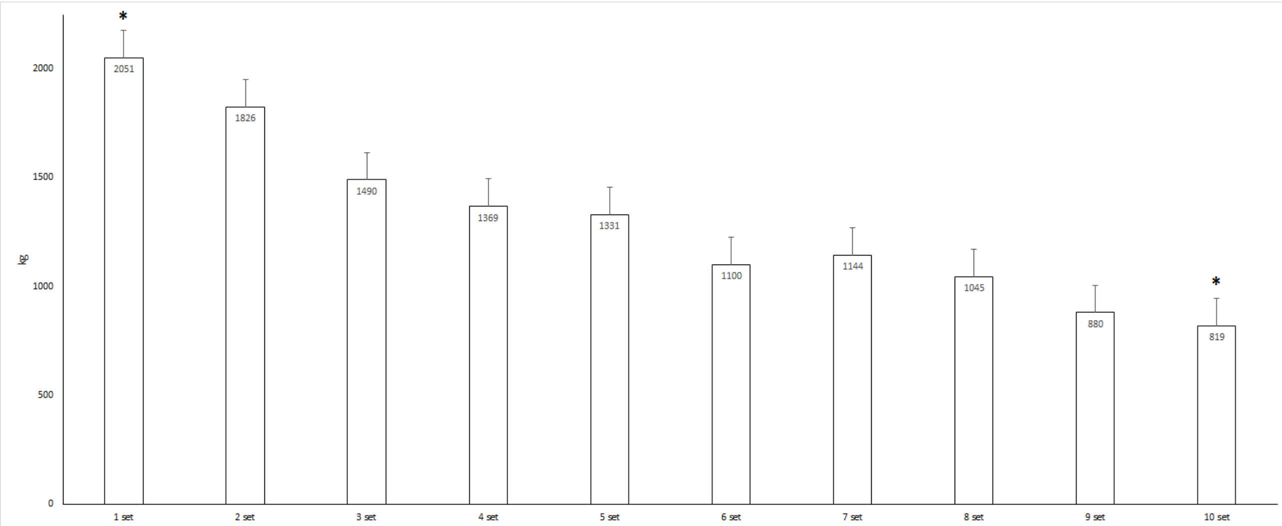

Fig. 1. Changes in volume of the load lifted in particular sets of the bench press exercise protocol

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 reps.	Last 3 reps.	First 3 reps.	Last 3 reps.
	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

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 ($p = 0.001$; $d = 0.884$), the lateral head of triceps brachii ($p = 0.001$; $d = 0.874$), and the long head of triceps brachii ($p = 0.001$; $d = 0.587$).

DISCUSSION

Resistance training has been recognized 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 above mentioned variables can be manipulated by the coach to induce specific adaptive changes necessary for particular athletes [20, 21]. Numerous sports disciplines require a high level of local muscular endurance. These include combat sports, swimming, rowing, speed skating and cycling. Training for the improvement in 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 with 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 above-mentioned 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 case of resistance training, central fatigue is poorly investigated and recognized [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 [24]. During the bench press, the activity of the pectoralis major (PM), anterior deltoid (AD) and triceps brachii (TB) increase along with the load and the speed of movement [24]. Changes in EMG activity of the prime movers are insufficiently investigated in resistance exercises with a constant external load performed to concentric failure, what justifies the conducted research.

This study 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 1st and the 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 in a significant drop in the total weight lifted in particular sets.

We observed a gradual and significant decrease in the number of repetitions and the amount of weight lifted in successive sets of the BP exercise protocol. The total value decreased almost threefold 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 equaled 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 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 number 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 a central and a 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 the load lifted in the 10th, last set of the exercise protocol.

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