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Analiza struktury wewnętrznej wyciskania sztangi leżąc

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Spis treści

1 WPROWADZENIE

Wyciskanie sztangi leżąc to pierwotnie konkurencja trójboju siłowego, która obecnie stanowi odrębną dyscyplinę sportu. W dyscyplinie tej rozgrywane są zarówno Mistrzostwa Świata, jak i Mistrzostwa Europy (Stastny i wsp. 2017). Wyciskanie sztangi leżąc, jest ćwiczeniem górnej części ciała, w którym można stosować znaczne obciążenia zewnętrzne, przy jednoczesnej wysokiej aktywacji nerwowo – mięśniowej. Potencjał wyciskania sztangi leżąc, w zakresie rozwoju siły mięśniowej sprawił, że jest to ćwiczenie wykorzystywane do celów szkoleniowych, testowych i badawczych (Anderson i Behm 2004, Lagally i wsp. 2004, Lehman 2005, Welsch i wsp. 2005, Gołaś i wsp. 2018). Skuteczność tego ćwiczenia w generowaniu siły mięśni zależy od: zmiany obciążenia, prędkości wykonywania ćwiczenia (Sakamoto i Sinclair 2012), liczby powtórzeń (Sundstrup 2012) oraz przerw wypoczynkowych między seriami (Strońska i wsp. 2019).

Badanie struktury wewnętrznej ruchu poprzez ocenę aktywności bioelektrycznej mięśni (Król 2003) w sporcie jest bardzo istotne, a elektromiografia (EMG) jest pośrednią, a zarazem jedyną metodą w ocenie wzorców rekrutacyjnych mięśni (Barnett i wsp. 1995). Elektromiografia jest metodą związaną z uzyskiwaniem, nagrywaniem i analizą sygnałów mioelektrycznych, powstających wskutek zmian fizjologicznych w strukturze błon komórkowych włókien mięśniowych (Konrad 2006). Podstawową korzyścią wynikającą z tego badania jest doskonalenie wzorca ruchowego.

Wzrost aktywności mięśniowej następuje w wyniku większej liczby zrekrutowanych jednostek motorycznych oraz zwiększonej częstotliwości pobudzeń, koniecznych do osiągnięcia ich napięcia (Lagally i wsp. 2004). Skurcz mięśnia powstaje w wyniku zmiany jego potencjału ze spoczynkowego na czynnościowy. Im więcej zaangażowanych jednostek motorycznych, tym większa aktywność bioelektryczna mięśnia (Stastny i wsp. 2017).

Badania wskazują, iż podczas wyciskania sztangi leżąc, aktywowane są głównie 4 grupy mięśniowe: mięsień piersiowy większy (pectoralis major), mięsień naramienny (anterior deltoid) oraz mięsień trójgłowy ramienia, zarówno głowa boczna (triceps brachii lateral), jak i głowa długa (triceps brachii long); (Trebs i wsp. 2010; Gołaś i wsp. 2016). Dzieje się tak, ze względu na napędowe i stabilizujące funkcje tych mięśni. Systematyczny trening oporowy, realizowany zgodnie z zasadami metodyki treningu siły mięśniowej, w istotny sposób usprawnia mechanizmy nerwowo-mięśniowe, poprzez zwiększenie liczby pobudzanych jednostek motorycznych lub/ i częstotliwość ich pobudzania (Lagally i wsp. 2004). W konsekwencji prowadzi to do wytworzenia większej siły mięśniowej. W treningu oporowym istotnym elementem jest kontrola nerwowo-mięśniowa wzorca ruchowego. Włókna mięśniowe, które nie są rekrutowane, nie uzyskują korzyści z danego ćwiczenia lub zadania. Wzrost aktywności mięśni wywołany większym obciążeniem zewnętrznym stanowi bezpośredni efekt adaptacji wysiłkowej (Gołaś i wsp. 2018). To zjawisko obserwuje się zarówno u sportowców, jak i u osób początkujących, co zostało wykazane w badaniu Lagally i wsp. (2004). Ze względu na różne proporcje włókien wolno i szybko kurczliwych oraz określony poziom rekrutacji zaangażowanych jednostek motorycznych, występują odmienne wzorce aktywności mięśniowej pomiędzy poszczególnymi zawodnikami (Gołaś i wsp. 2016).

Lagally i wsp. (2004) opisali aktywność mięśni obręczy barkowej, podczas wyciskania sztangi leżąc u kobiet. Stwierdzili, że zmiana obciążenia z 60% na 80% 1 powtórzenia maksymalnego (1RM – one repetition maximum) prowadzi do istotnego wzrostu aktywności jedynie mięśnia piersiowego.

Niektórzy autorzy wskazują, że na wzorzec ruchu w wyciskaniu sztangi leżąc, istotnie wpływa kąt nachylenia ławki (Stastny i wsp. 2017), dlatego istnieje bezpośredni związek pomiędzy umiejscowieniem jednostek ruchowych w mięśniu a określonymi wzorcami ruchu (Glass i Armstrong 1997). Różne części mięśnia można aktywować selektywnie, zwiększając w ten sposób liczbę i częstotliwość rekrutowanych jednostek motorycznych. Zgodnie z założeniami Flecka i Kraemera (2014), selektywny trening oraz zwiększona częstotliwość aktywacji, powodują hipertrofię różnych obszarów mięśnia.

Z kolei Barnett i wsp. (1995), zbadali zintegrowaną elektromiograficzną (TEMG) aktywność górnej i środkowej części mięśnia piersiowego, podczas wyciskania sztangi leżąc na ławce płaskiej i skośnej. Okazało się, że podczas wyciskania sztangi na ławce płaskiej, występuje większa ogólna aktywacja mięśnia piersiowego. Ławka skośna w górę aktywuje górną część (obojczykową) mięśnia piersiowego (Egger 1989), natomiast część dolna (mostkowa) bardziej aktywowana jest, podczas wyciskania sztangi leżąc na ławce skośnej w dół (Barnett 1995, Glass i Armstrong 1997).

W odniesieniu do zmienności odległości pomiędzy ramionami zauważono, iż szerszy chwyt wymaga większej aktywności mięśnia piersiowego, podczas gdy wąski chwyt aktywuje w większym stopniu mięsień trójgłowy ramienia. Szerokość uchwytu ma zatem istotny wpływ na aktywację mięśnia piersiowego (Egger 1989) oraz mięśnia naramiennego (McLaughlin 1984).

Zmiana aktywności mięśniowej jest uzależniona również od skupienia uwagi na aktywacji określonej grupy mięśniowej (Calatayud i wsp. 2016). Literatura donosi, że wewnętrzne skupienie uwagi może zwiększyć amplitudę EMG przy intensywnościach od 20 do 60% 1RM, podczas wyciskania sztangi leżąc, przy kontrolowanych prędkościach (Calatayud i wsp. 2016; Snyder i Fry 2012). Calatayud i wsp. (2017) stwierdzili, że wewnętrzne skupienie mentalne, kolejno na mięśniu piersiowym oraz mięśniu trójgłowym ramienia, zwiększyło ich aktywność w porównaniu ze standardową koncentracją uwagi, podczas wyciskania sztangi leżąc przy kontrolowanej prędkości. Niektórzy autorzy sugerują, iż wewnętrzne skupienie poprawia poziom koordynacji nerwowo-mięśniowej w pracujących mięśniach (McNevin i Wulf 2002; Zachry i wsp. 2005). Sakamoto i Sinclair (2012) stwierdzili, że większe prędkości podczas ćwiczenia wyciskania sztangi leżąc, zwiększają średnią amplitudę EMG w całej fazie koncentrycznej, w porównaniu z wolniejszymi prędkościami. W porównaniu z mniejszymi prędkościami dynamiczne skurcze wykazały niższe progi rekrutacji (Desmedt i Godaux 1977). Z kolei Calatayud i wsp. (2017), stwierdzili, że podczas trwania skurczu <1,3 s., użycie różnych skupień uwagi nie miało wpływu na amplitudę EMG.

Uwzględniając powyższe rozważania, struktura wewnętrzna wyciskania sztangi leżąc, jest dobrze opisana (Ojasto i Häkkinen 2009, Sakamoto i Sinclair 2012, Stastny 2017), jednak w literaturze brakuje informacji, na temat zmiany aktywności pracujących mięśni pomiędzy kobietami i mężczyznami, w zależności od zmieniającego się obciążania oraz różnic w stopniu zaangażowania pracujących mięśni, podczas wysiłku do koncentrycznej niewydolności. Szczegółowy przegląd literatury wskazuje także na brak prac naukowych, w których można by, doszukać się analizy wzorca aktywności w wyciskaniu sztangi leżąc, po ukierunkowanym, indywidualnie zaplanowanym okresie treningu siły mięśniowej. Wyniki uzyskane z powyższych analiz umożliwiają pełniejszą analizę i ocenę zmian wzorca aktywności mięśni, podczas wyciskania sztangi leżąc.

W przedstawionym cyklu prac głównym problemem badawczym jest wykorzystanie elektromiografii powierzchniowej do analizy i oceny wzorca aktywności mięśniowej, podczas wyciskania sztangi leżąc na ławce płaskiej. Prace te, zostały przedstawione pod wspólnym tematem: **Analiza struktury wewnętrznej wyciskania sztangi leżąc.**

Celem przedstawionego cyklu trzech prac jest analiza następujących zagadnień:

1 – analiza i ocena różnic aktywności mięśniowej w wyciskaniu sztangi leżąc na ławce płaskiej pomiędzy kobietami i mężczyznami.

2 – analiza i ocena zmian aktywności mięśniowej w wyciskaniu sztangi leżąc w 10 seriach tego ćwiczenia, wykonanych do odmowy.

3 – analiza zmian wzorca aktywności mięśniowej podczas wyciskania sztangi leżąc na skutek ukierunkowanego, 6 tygodniowego treningu oporowego.

2 CHARAKTERYSTYKA OSIĄGNIĘCIA NAUKOWEGO – OCENA BIBLIO METRYCZNA

Podstawą przewodu doktorskiego jest osiągniecie naukowe w postaci 3 prac empirycznych wchodzących w skład cyklu, dotyczącego analizy struktury wewnętrznej wyciskania sztangi leżąc.

Biometryczne podsumowanie jednotematycznego cyklu 3 prac:

IF= 3,916; MNSiW = 160 pkt. KBN,

Wykaz prac opublikowanych:

1. Artur Gołaś, Adam Maszczyk, Michał Wilk, Petr Stastny, **Katarzyna Strońska**, Marcin Studencki, Adam Zając. Muscular activity patterns of female and male athletes during the flat bench press. *Biology of Sport* Vol 35, nr 2 (2018), s. 175-179. **[IF = 2,202, MNiSW = 70 pkt. KBN]**

2. **Katarzyna Strońska,** Marta Trebert, Artur Gołaś, Adam Maszczyk, Adam Zając. Changes in EMG activity of the prime movers during 10 sets of the flat bench press performed to concentric failure**.** *Baltic Journal of Health and Physical Activity* Vol. 10, nr 1 (2018), s. 22-29. **[IF = 0, MNiSW = 20 pkt. KBN]**

3. **Katarzyna Strońska,** Artur Gołaś, Adam Zając, Adam Maszczyk, Michał Wilk, Petr Stastny. The effect of targeted resistance training on bench press performance and the alternation of prime more muscle activation patterns. *Sports Biomechanics*. **[IF = 1,714, MNiSW = 70 pkt. KBN]**

3 BADANIE 1

Opublikowana w czasopiśmie *Biology of Sport* praca pt. **„Zmiana wzorca aktywności mięśniowej pomiędzy mężczyznami i kobietami w wyciskaniu sztangi leżąc" (Muscular activity patterns of female and male athletes during the flat bench press)**, pozwoliła wykazać odmienną strukturę wewnętrzną pomiędzy kobietami i mężczyznami, podczas wyciskania sztangi leżąc na ławce płaskiej, w zależności od obciążenia zewnętrznego. W eksperymencie uczestniczyło 5 mężczyzn i 5 kobiet. Dobór do badań miał charakter celowy i obejmował osoby z przynajmniej rocznym doświadczeniem, w treningu wyciskania sztangi leżąc na ławce płaskiej. Wiek badanych, wysokość i masa ciała wynosiły odpowiednio dla mężczyzn 21,3 ± 2.6lat 181.4 ± 8 cm, 85 ± 11.3 kg oraz dla kobiet 21.8 ± 1.9 lat, 165 ± 5.8 cm, 69,7 ± 5,9 kg.

Stwierdzono, iż u mężczyzn znaczny wzrost aktywności mięśnia piersiowego większego zaobserwowano przy obciążeniu zewnętrznym 80% 1 RM (Anderson i Behm 2004, Welsch i wsp. 2005, Santana i wsp. 2007), podczas gdy wzrost aktywności tego mięśnia u kobiet, wystąpił nawet przy maksymalnym obciążeniu zewnętrznym. Wyniki uzyskane w tych badaniach pokazują, że wzrost obciążenia z 55% do 100% 1RM podczas wyciskania sztangi leżąc, u mężczyzn prowadzi do zwiększenia aktywności mięśnia trójgłowego ramienia (głowy długiej) i mięśnia naramiennego (części przedniej), z najbardziej znaczącymi zmianami w mięśniu naramiennym. Natomiast u kobiet, wzrost obciążenia z 55% do 100% 1RM spowodował istotny statystycznie wzrost aktywności mięśnia naramiennego (części przedniej) oraz mięśnia piersiowego większego. Cechą wspólną sportowców płci męskiej i żeńskiej jest zasadnicza aktywność mięśnia naramiennego. Większość badań związanych z wykorzystaniem EMG w wyciskaniu sztangi leżąc, potwierdza znaczące zaangażowanie mięśnia naramiennego w tym ćwiczeniu, niezależnie od poziomu sportowego badanych (Snyder i Fry 2012). Można stwierdzić, iż różnice osobnicze w aktywności mięśniowej pomiędzy kobietami i mężczyznami, mogą wynikać z niższego poziomu siły kończyny górnych (mniejsza masa mięśniowa, słabsze więzadła wokół ramienia i stawów łokciowych) u kobiet, które powodują niższą aktywność mięśnia trójgłowego ramienia (zarówno głowy bocznej, jak i głowy długiej) w porównaniu do mężczyzn. Należy jednak podkreślić, iż maksymalne pobudzenie mięśniowe uzyskujemy na obciążeniach submaksymalnych i maksymalnych, w związku z tym, wzorzec aktywności mięśniowej najlepiej porównywać na tych obciążeniach (Król i Gołaś 2017). Dotychczasowa literatura naukowa udowadnia, że przy wzroście obciążeń w kierunku wartości submaksymalnych i maksymalnych zwiększa się aktywność mięśnia trójgłowego ramienia (Trebs i wsp. 2010, Van den Tillaar i Saeterbakken 2013).

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Muscular activity patterns of female and male athletes during the flat bench press

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ABSTRACT: The bench press (BP) is a complex upper body exercise in which substantial external loads can be used, demanding high neuromuscular activity. The aim of this study was to compare electromyographic (EMG) activity between female and male athletes during the flat bench press. Five male and five female athletes participated in this study. The main session included four sets of one repetition of the flat bench press with the load of 55, 70, 85 and 100% of the one-repetition maximum (1RM). The activity of four muscles was analysed: the pectoralis major (PM), the anterior deltoid (AD), the lateral head of the triceps brachii (TBlat) and the long head of the triceps brachii (TBlong). The main finding of the study was that the muscle activity pattern differed between women and men during the bench press depending on the external load. The non-parametric Kruskal-Wallis ANOVA for males showed differences between the TLpeak values recorded for different loads (55%-100% 1RM) during the bench press (chi-square = 15.3, p = 0.009) and AD_{peak} (chi-square = 19.5, p = 0.001). The non-parametric Kruskal-Wallis ANOVA for females showed differences between the AD_{peak} values recorded for different loads (55%-100% 1RM) during the bench press (chi-square = 12.1, p = 0.018).

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Key words:
Bench press
EMG
Resistance exercise
Testing

INTRODUCTION

Training to increase neuromuscular fitness has been shown to be effective in improving athletic performance [1]. Neuromuscular training consists of overcoming external resistance using internal strength, with multiple sources of resistance available, such as dumbbells, barbells, as well as elastic, pneumatic and hydraulic resistance [2]. The bench press (BP) is a complex upper body exercise in which substantial external loads can be used, demanding high neuromuscular activity. The potential of the BP for strength development and popularity of BP competitions have made it a unique phenomenon as a popular exercise for training, testing or research purposes. Athletes are often involved in specific training programmes that can change the proportions of strength in different muscle groups. Interesting insight into these problems can be derived from the topography of muscle strength that describes how particular groups of muscles contribute to total strength. Scientists and coaches are interested in how maximum strength, explosive strength or power output can be improved using the BP exercise and how muscle activity changes for BP variations [3].

The neuromuscular recruitment has been assessed only by the EMG amplitude to observe the influence of exercise load as an external stimulus to provide a greater training stimulus to muscles. That is, only the tonic aspect of neurophysiologic behaviour of motor units during muscular contraction related to intensity of muscular activation has been considered. Two previous reviews have been written to answer these questions. The first review evaluated the criteria for BP efficiency and safety that can be recommended for strength conditioning programmes [4, 5], while the second one provided a meta-analysis of the studies focused on optimal load for power training [6, 7].

Depending on the method used to perform the bench press exercise, the following three muscle groups are primarily involved: the pectoralis major (PM), the anterior deltoid (D) and the triceps brachii (TB) [8, 9]. The change in the load affects the pattern of muscle activity during this exercise [10]. The root mean square (RMS) value provides information about the geometric (amplitude) and temporal characteristics of motor unit behaviour during muscular contraction. It is important to understand the tonic and phasic characteristics of neuromuscular stimuli to control the performance under different external loads. Although internal movement structure has been described extensively in the literature concerning the bench press [11,12,13], no studies have compared muscle activity patterns between female and male athletes. The main aim of this study was to compare the muscular activity patterns between male and female athletes during the flat bench press. The specific aims were to evaluate differences in muscular activity patterns between female and male athletes at various external loads during the bench press and to determine the muscle groups which show the most significant differences between female and male athletes.

MATERIALS AND METHODS

Participants

Five male (age: 21 years; body height: 177 ± 8 cm, body mass: 85 ± 11 kg, 1RM bench press: 105 15 kg) and five female (age: 21 years; body height: 165 ± 8 cm; body mass: 69.7 ± 5.9 kg, 1RM bench press: 55 ± 10 kg) athletes with at least one year of bench press training experience participated in the study. The participants did not perform any resistance training 72 hours prior to testing to avoid fatigue. All the subjects were informed verbally and in writing about the procedures, as well as the possible benefits and risks of the tests and provided written consent before they were included in the study. The study received the approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland.

Procedures

The measurements were performed in the Strength and Power Laboratory at the Academy of Physical Education in Katowice. There were two sessions of the experiment. A standardized warm-up protocol was used for each session, including a general warm-up (5 min) performed on a hand cycle ergometer (heart rate 130-140 bpm). The specific part of the warm-up consisted of three bench press sets with the load adjusted to perform 15, 10 and 5 repetitions. The first session was aimed at determination of the one-repetition maximum in the flat bench press (1RM). The second session included four sets of one repetition of the flat bench press with the load of 55, 70, 85 and 100% of 1RM. The activity of four muscles was analysed: the pectoralis major (PM), the anterior deltoid (AD), the lateral head of the triceps brachii (TBlat) and the long head of the triceps brachii (TBlong).

Measurements

An eight-channel Noraxon TeleMyo 2400 system (Noraxon USA Inc., Scottsdale, AZ; 1500 Hz) was used for recording and analysis of electric potentials from the muscles. The activity was recorded for four muscles: the pectoralis major (sternocostal fibres), the anterior deltoid, the triceps brachii (lateral head) and the triceps brachii (long head). Before placing the 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 fibres according to the recommendations of Seniam [14]. 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. The rate of all exercises was controlled by an electronic metronome (Korg MA-30, Korg, Melville, New York, USA). Analysis was based on peak muscular activity during the BP (both from the eccentric and concentric phases).

Statistical Analysis

Data normality was tested with the Shapiro-Wilk test. Changes in the activity of the muscles during the flat bench press for different loads were analysed using the Kruskal-Wallis non-parametric ANOVA [15]. Post-hoc tests were used to analyse statistically significant changes. Fixed-base indices were employed to evaluate changes in muscle activity. All statistical analyses were conducted by means of the STATISTICA 9.1 package and MS Excel 2010.

RESULTS

The non-parametric Kruskal-Wallis ANOVA for females showed differences between the ADpeak values recorded for different loads during the bench press (chi-square = 12.1, p = 0.018). As shown by the results of the post-hoc tests, the greatest differences occurred for the load of 55% of 1RM and 100% of 1RM (p = 0.044).

The non-parametric Kruskal-Wallis ANOVA for male athletes showed differences between the TLpeak values recorded for different loads during the bench press (chi-square = 15.3, p = 0.009). As shown by the results of the post-hoc tests, the greatest differences occurred for the load of 55% of 1RM and 100% of 1RM (p = 0.033). Variations were also found in the ADpeak values recorded for different loads during the bench press (chi-square = 19.5, p = 0.001). As shown by the results of the post-hoc tests, the greatest differences occurred for the load of 55% of 1RM and 100% of 1RM (p = 0.021).

TABLE 1. Peak muscle activity for the PM, AD, $TBlat_{peak}$ and $TBlong_{peak}$ muscles during the bench press exercise performed by female and male athletes with the load of 55%, 70%, 85% and 100% 1RM.

	55% 1RM	70% 1RM	85% 1RM	100% 1RM
FEMALES				
AD_{peak}	90	119	125	151
PM_{peak}	65	67	85	95
$TBlat_{peak}$	51	55	67	68
$TBlong_{peak}$	55	59	62	75
MALES				
AD_{peak}	67	79	90	117
PM_{peak}	70	72	90	89
$TBlat_{peak}$	65	71	85	89
$TBlong_{peak}$	95	124	141	165

Note: the one-repetition maximum - 1RM; the pectoralis major - (PM); the anterior deltoid - (AD); the lateral head of the triceps brachii - (TBlat); the long head of the triceps brachii - (TBlong).

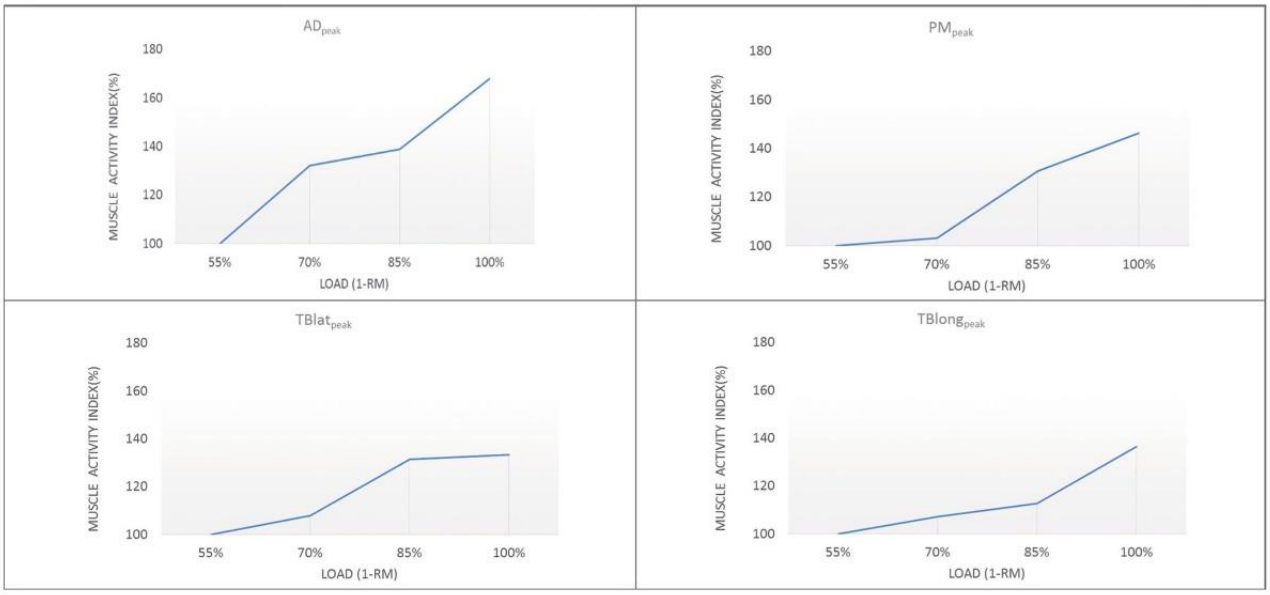

FIG. 1. Muscle activity index (%) for AD_{peak}, PM_{peak}, $TBlat_{peak}$, $TBlong_{peak}$ by female athletes during the flat bench press with a load of 55%, 70%, 85% and 100% 1RM.
Note: the pectoralis major - (PM); the anterior deltoid - (AD); the lateral head of the triceps brachii - (TBlat); the long head of the triceps brachii - (TBlong).

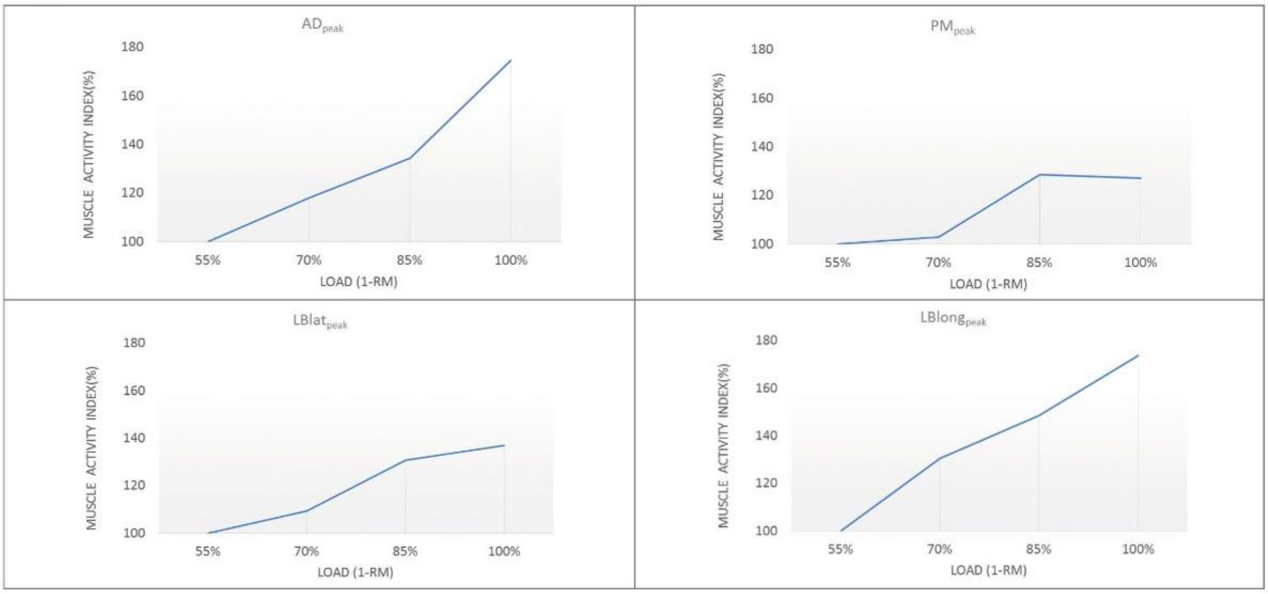

FIG. 2. Muscle activity index (%) for AD_{peak}, PM_{peak}, $TBlat_{peak}$, $TBlong_{peak}$ by male athletes during the bench press with a load of 55%, 70%, 85% and 100% 1RM.
Note: the pectoralis major - (PM); the anterior deltoid - (AD); the lateral head of the triceps brachii - (TBlat); the long head of the triceps brachii - (TBlong).

DISCUSSION

The aim of this study was to compare electromyographic activity between female and male athletes during the flat bench press. The main finding of the study is that the muscle activity pattern differs between women and men during the bench press depending on the external load. The electromyographic data determine whether the muscle is active, the level of muscle activity, how the muscles work together and whether muscular fatigue occurs [16]. The main aim of the study was to identify the pattern, i.e. to determine the muscle activity expressed by the percentage contribution of the activity to the specific exercise.

According to Sakamoto and Sinclair [11], once a strategy set by the central nervous system to perform a motor task is chosen, it is implemented by activation of a group of muscles in the appropriate sequence. The selection of the correct muscles to be activated is simplified by certain principles [17, 18]. One of these principles is directed at optimizing muscle coordination in order to minimize energy expenditure. Another principle is related to the prediction of forces such as gravity or inertial interactions among body segments [19]. The motor unit recruitment and firing rate to execute intended movements are regulated by the descending command from the central nervous system and can be modulated by afferent feedback during muscular weakness or fatigue [20]. The activity was recorded for the most important muscles of the shoulder girdle [21] involved in the bench press. These include the pectoralis major (the sternal head), deltoid (anterior head) and triceps brachii (the lateral and long head). Numerous authors [22, 23, 24, 25] have confirmed that these muscles are most frequently emphasized during the BP due to their propulsive or stabilizing functions. The internal structure (level and time of bioelectrical activity of the muscles) during the flat bench press reflects the action of muscular forces, which are, apart from the gravity forces, the main cause of the movement of upper limbs and the weight. The increase in muscle load is naturally followed by increased recruitment of motor units and higher excitation frequency in order to achieve the necessary contraction [23]. Consequently, this leads to generation of greater force. The increase in muscle activity caused by greater load represents a direct effect of the enhanced efferent motor activity. As the load rises, an increase in muscular activity is observed not only in professional and amateur athletes but also in beginners, which was demonstrated in a study by Lagally et al. [23].

The increase in muscle activity in female athletes from the load of 55% to 100% of 1RM is 67.8% for the deltoid muscle, 46.2% for the pectoralis major, 33.3% for the lateral head of the triceps brachii and 36.4% for the long head of the triceps brachii. In men, the changes in EMG during progressive loads (from 55% to 100% 1RM) were as follows: 74.6% for the deltoid muscle, 27.1% for the pectoralis major, 36.9% for the lateral head of the triceps brachii and 73.7% for the long head of the triceps brachii. The ability of the central nervous system to use afferent feedback to modulate intended movements during muscular weakness may explain the increase in motor unit recruitment. The increase of load in a particular muscle or a certain muscle group affects the tonic neuromuscular recruitment patterns of synergists to maintain the required performance. This modulation by afferent feedback involves the remarkable adaptability of the synaptic short-term physiological and biochemical changes [26].

The results of this study are consistent with previous studies concerning the flat bench press. However, our study is one of the first to indicate that the movement structure of the flat bench press differs significantly between women and men. The activity during push exercises performed by women was examined by Lagally et al. [23], who demonstrated that the triceps brachii muscle was involved to a greater extent than the pectoralis major and deltoid muscles in the bench press exercise. This finding was reproduced when the load was increased from 60% to 80% of 1RM in both well-trained and beginner female athletes. However, it should be emphasized that the maximal use of BP technique can be utilized only at maximal and submaximal loads, when the objective is to positively complete the exercise [27].

Muscle activity normalized with respect to maximal potential under static conditions (%) helped fully evaluate the effects of increased load on muscle behaviour. Changes in the pattern of muscle activity during the bench press have been well described in the literature, yet no studies have compared EMG activity between women and men. In most of the studies that have examined men, the increase in the activity in the pectoralis major muscle was noticeable from the load of 80% of 1RM [21, 24, 25], whereas the increase in activity of this muscle in women occurred even at the maximal load. The results obtained in our study show that the increase in the load from 55% to 100% of 1RM during the flat bench press in men leads to an increase in activity of the triceps brachii muscle (long head) and the deltoid muscle (anterior head), with the most significant changes in the deltoid muscle.

The common feature of male and female athletes during the bench press is the substantial activity of the deltoid muscle. Most studies related to EMG activity in the bench press confirm significant involvement of the anterior deltoid in this exercise, regardless of the sports level of the study participants. Snyder and Fry [28] found that three parts (heads) of the deltoid muscle are activated in all shoulder movements, with one head that acts as a source (driving force) of propulsion and the other involved in stabilization of the humerus on the articular facet. They also suggested that this approach should be used for the analysis of activity of all the muscles in resistance training. Several studies have demonstrated that the change from the free barbell bench press to the Smith machine bench press leads to an increase in activity of all the muscle groups around the shoulder, which eliminates the necessity of using the anterior and medial heads of the deltoid muscle to counteract the supination and adduction of the humerus [29].

The results presented in this study have certain limitations. First of all, the sample studied was rather small and thus far-reaching conclusions are not possible. Secondly, the electromyographic signal from the muscles studied could have varied due to the different sports levels and different BP techniques of the study participants. Further research should focus on a larger, more homogeneous group of subjects, and should take into consideration changes in the pattern of muscular activity in the flat bench press after a specific training programme. Changes in tonic control as a result of muscular weakness can cause changes in movement techniques; therefore future studies need to include measurements of the external structure of movement (acceleration, velocity, displacement).

CONCLUSIONS

The differences in EMG changes with progressive loads between male and female athletes may result from the lower level of strength of the upper limbs (lower muscle mass, weaker ligaments around the shoulder and elbow joints) in women caused by lower activity of the triceps brachii muscle compared to men. Changes in tonic control as a result of muscular work can cause changes in movement techniques. These changes may be related to limited ability to control mechanical loads and mechanical energy transmission to joints and passive structures [26].

Acknowledgements

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4 BADANIE 2

Praca opublikowana w czasopiśmie *Baltic Journal of Health and Physical Activity* pt. **„Zmiana wzorca aktywności mięśniowej podczas 10 serii wyciskania sztangi leżąc wykonywanych do koncentrycznej niewydolności" (Changes in EMG activity of the prime movers during 10 sets of the flat bench press performer to concentric failure)** pozwoliła na określenie zmiany wzorca aktywności poszczególnych grup mięśniowych, zaangażowanych w wyciskanie sztangi leżąc na ławce płaskiej, podczas 10 serii tego ćwiczenia, wykonywanych do koncentrycznej niewydolności. W badaniu wzięło udział 10 mężczyzn, z co najmniej 5- letnim doświadczeniem w treningu siły mięśniowej. Dobór do badań miał charakter celowy. Wiek, masa oraz wysokość ciała wynosiły odpowiednio 32 ± 4 lat, 86.3 ± 5.2 kg, 181.3 ± 4.2 cm, a średnia 1RM wynosiła 112,5 ± 12.6 kg.

Wielostawowe ćwiczenia oporowe, wykonywane z umiarkowanym obciążeniem (60% 1RM) do koncentrycznego upadku mięśniowego, mogą spowodować znaczne, ostre zmęczenie centralnego i obwodowego układu nerwowego (Zając i wsp. 2015). Spadek generowanej siły mięśniowej jest efektem zmniejszonej aktywności bioelektrycznej oraz zaburzenia równowagi kwasowo-zasadowej krwi i mięśni (Gandevia 2001, Takada i wsp. 2012, Zając i wsp. 2015). W przypadku treningu oporowego centralne zmęczenie jest słabo zbadane (Zając i wsp. 2015). W tym badaniu podjęto próbę oceny zmian aktywności EMG wiodących grup mięśniowych, podczas 10 serii wyciskania sztangi leżąc, z których każda została wykonana do koncentrycznej niewydolności. Porównano aktywność EMG każdego mięśnia oddzielnie oraz ich całkowitą aktywność pomiędzy pierwszymi trzema a trzema ostatnimi powtórzeniami pierwszej i dziesiątej serii. Protokół badań miał charakter nowatorski, gdyż w eksperymencie uczestniczyli sportowcy z dużym stażem treningowym, których poddano ekstremalnemu wysiłkowi w postaci dziesięciu serii wyciskania sztangi leżąc, wykonanych do niewydolności mięśniowej. Obserwowano stopniowy i istotny spadek liczby powtórzeń w kolejnych seriach ćwiczenia. Łączna ich liczba zmniejszyła się prawie trzykrotnie pomiędzy pierwszą a dziesiątą serią protokołu badań, co wskazuje na systematyczny wzrost zmęczenia. W pierwszej serii ćwiczenia zawodnicy wykonali średnio 24-25 powtórzeń, a wszystkie badane mięśnie zwiększyły napięcie, począwszy od pierwszych trzech, do trzech ostatnich powtórzeń. Ponieważ zastosowane obciążenie wynosiło tylko 60% 1RM, napięcie wiodących mięśni było relatywnie niskie, w pierwszych trzech powtórzeniach wyciskania sztangi leżąc. Napięcie tych mięśni wzrastało istotnie w kolejnych powtórzeniach ćwiczenia, osiągając znacznie wyższe wartości w ostatnich powtórzeniach danej serii, kiedy centralny układ nerwowy (CUN) był zmuszony zwiększyć częstotliwość pobudzenia, aby pokonać obciążenie w warunkach postępującego zmęczenia obwodowego (Enoka i Duchateau 2008). W dziesiątej, ostatniej serii wyciskania sztangi leżąc, zawodnicy wykonali średnio tylko 8-9 powtórzeń, a aktywność wszystkich badanych mięśni istotnie zmniejszyła się w stosunku do pierwszej serii ćwiczenia. Ograniczoną liczbę powtórzeń wykonanych w ostatniej serii oraz brak możliwości zwiększenia napięcia w kolejnych powtórzeniach można wytłumaczyć zmęczeniem CUN i kumulacją ubocznych produktów metabolizmu wysiłkowego (Zając i wsp. 2015). Można stwierdzić, iż zmęczenie obwodowe ogranicza liczbę powtórzeń w pierwszych seriach tego ćwiczenia, podczas gdy centralne zmęczenie kumuluje się z każdą kolejną serią, powodując znaczny spadek aktywności elektromiograficznej, co widoczne jest w ostatnim powtórzeniu dziesiątej serii tego ćwiczenia.

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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).

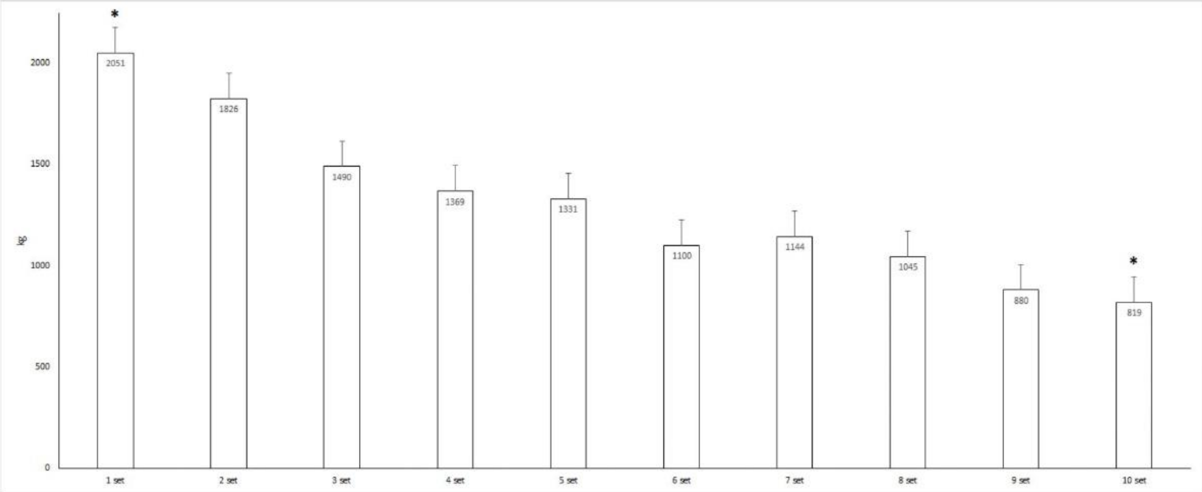

Fig. 1. Changes in volume of the load lifted in particular sets of the bench press exercise protocol

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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5 BADANIE 3

Praca pt. **„Wpływ ukierunkowanego treningu oporowego na wzorzec aktywności mięśniowej podczas wyciskania sztangi leżąc” (The effect of targeted resistance training on bench press performance and the alternation of prime mover muscle activation patterns)**, opublikowana została w czasopiśmie *Sports Biomechanics*. Głównym problemem badawczym tego eksperymentu, było określenie zmian aktywności mięśniowej pod wpływem 6 tygodniowego, ukierunkowanego treningu wiodących grup mięśniowych w obrębie stawu ramiennego, biorących udział w wyciskaniu sztangi leżąc na ławce płaskiej.

W eksperymencie wzięło udział 27 mężczyzn. Dobór do badań miał charakter mieszany (losowy i celowy) i obejmował zawodników z co najmniej 5-letnim doświadczeniem w treningu oporowym, z dobrze opanowaną techniką wyciskania sztangi leżąc. Ich wiek, masa ciała i wysokość wynosiły odpowiednio 26 ± 7.6 lat, 87.3 ± 10.2 kg, 179.3 ± 11.2 cm. Spośród 27 osób zakwalifikowanych do eksperymentu 10 sportowców wykazało najniższą aktywność w mięśniach trójgłowych ramienia (głowa długa), 8 miało najniższą aktywność mięśnia piersiowego większego, a 9 pozostałych sportowców charakteryzowała najniższa aktywność mięśni naramiennych. Poprzez ukierunkowany trening oporowy podjęto próbę oceny aktywności mięśni: piersiowego większego, trójgłowego ramienia (głowy długiej) oraz przedniej części mięśnia naramiennego. Celem niniejszych badań było określenie wpływu 6 tygodniowego, ukierunkowanego treningu oporowego, na aktywność wiodących grup mięśniowych, biorących udział w wyciskaniu sztangi leżąc.

Najważniejszym osiągnięciem tego badania był fakt, iż 6-tygodniowy, ukierunkowany trening oporowy wpłynął na czasowy wzorzec koncentrycznej i izometrycznej aktywności mięśniowej, podczas wyciskania sztangi leżąc, co zwiększyło wartość 1RM. Można założyć, że identyfikacja najmniej aktywnych grup mięśniowych może być skuteczną metodą optymalizacji wyboru ćwiczeń i określenia, które grupy mięśniowe powinny zostać poddane selektywnej pracy treningowej. Niniejsze osiągnięcie jest zgodne z doniesieniami Häkkinena i wsp. (1987), gdzie u kulturystów uzyskano zmianę aktywności mięśni, na skutek selektywnego treningu oporowego. Z eksperymentu wynika, że wzrost aktywności mięśniowej występuje również w treningach ukierunkowanych na określone grupy mięśniowe.

Po selektywnym 6-tygodniowym okresie treningowym, ukierunkowanym na deficyt aktywności mięśniowej, wystąpił wzrost aktywności grup mięśniowych poddanych badaniu, który może być związany ze zmianami w tonicznej kontroli mięśni (Duchateau i Enoka 2011). Wzrost izometrycznej i dynamicznej aktywności mięśnia trójgłowego ramienia (głowy długiej) stwierdzono po ćwiczeniach ukierunkowanych na aktywację tego mięśnia, dlatego ćwiczenia takie, powinny być wysoce zalecane w praktyce trenerskiej. Wyjaśnieniem może być to, iż mięsień trójgłowy ramienia odgrywa ważną rolę w poprawie wyniku sportowego (Gołaś i wsp. 2017) i przezwyciężaniu punktu krytycznego w wyciskaniu sztangi leżąc na ławce płaskiej (Van den Tillaar i wsp. 2012). Innym wyjaśnieniem może być to, iż mięsień trójgłowy ramienia jest bardziej dystalną grupą mięśni kończyn górnych o bardziej izolowanej funkcji w porównaniu z mięśniem piersiowym większym czy naramiennym, a zatem może w większym stopniu być podatny na zmiany adaptacyjne wywołane treningiem priorytetu mięśniowego.

Brak poprawy izometrycznej aktywności przedniej części mięśnia naramiennego i mięśnia piersiowego większego (wraz z poprawą aktywności dynamicznej) może odnosić się do czasu potrzebnego na zmianę wzorca aktywności, co może być trudne do osiągnięcia, ze względu na wielopłaszczyznowe funkcje tych mięśni oraz w przypadku mięśnia piersiowego większego, duży obszar unerwienia (Drake i wsp. 2016). Ponadto, mięsień piersiowy większy jest rzadziej wykorzystywany w czynnościach życia codziennego, w porównaniu z mięśniem trójgłowym ramienia czy mięśniem naramiennym, co mogło przełożyć się na ograniczone wykorzystanie mięśnia piersiowego większego w ćwiczeniach wielostawowych.

Ukierunkowany trening mięśni jest skuteczną metodą zmniejszania deficytów aktywności mięśniowej i wzrostu siły mięśniowej w ćwiczeniach kompleksowych, w przypadku zastosowania treningu w grupach mięśni o niskiej aktywności elektromiograficznej. Trening ukierunkowany na wzmocnienie mięśnia trójgłowego ramienia wywołuje istotne zmiany w aktywności mięśniowej i powoduje dominację aktywności tego mięśnia, podczas wyciskania sztangi leżąc. Trening ukierunkowany na wzrost aktywności mięśnia piersiowego większego wydaje się mniej skuteczny w zwiększaniu zaangażowania tego mięśnia w stosunku do treningu ukierunkowanego na wzrost aktywności mięśnia naramiennego lub mięśnia trójgłowego ramienia. W praktyce zaleca się stosowanie ukierunkowanego treningu w celu wzrostu aktywności mięśnia trójgłowego ramienia, stosując następujące ćwiczenia: wyciskanie francuskie leżąc na ławce płaskiej, ściąganie linek wyciągu górnego oraz wyciskanie sztangielki w podporze.

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The effect of targeted resistance training on bench press performance and the alternation of prime mover muscle activation patterns

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ABSTRACT
Targeted muscle strengthening might improve performance or help overcome training stagnation; therefore, the aim of the present study was to investigate changes in muscle activity patterns before and after six weeks of targeted resistance training. Twenty-seven resistance-trained men were divided into three groups according to their prime mover activity, as measured by surface electromyography during a bench press (BP). Each group underwent a six-week block of targeted exercises for one of the following muscles: anterior deltoid (AD), pectoralis major (PM) or triceps brachii (TB). ANOVA showed that each group increased their 1 repetition maximum (1RM) ($p < 0.05$) and the activity of the exercised muscle group during an isometric bench press ($p < 0.01$) and during a dynamic bench press ($p < 0.01$) at 85% of the 1RM. During the isometric BP, the TB training group had an increase in TB activity in comparison to the other groups. Targeted muscle training is a useful method for muscle activity increase and increasing the maximum strength in complex exercise, when applied in activity-deficient muscle groups. Strengthening the TB elicits changes in all prime movers and results in TB activity domination during a bench press.

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KEYWORDS
Anterior deltoid; triceps brachii; pectoralis major; electromyography; intervention

Introduction

The analysis of muscle activity during complex exercise movement patterns is widely used to improve resistance training effectiveness, e.g. to improve bench press (BP) performance (Gołaś et al., 2018; Stastny et al., 2017; Vigotsky et al., 2017). The purpose of such analyses is to identify possible deficiencies in muscle activation or the most active muscle group when overcoming external resistance (Maszczyk et al., 2016; Van den Tillaar et al., 2012), which might help to improve performance, overcome training stagnation or prevent injury (Serner et al., 2014). If a lack of muscle activation or strength

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is found, coaches or other practitioners can apply targeted muscle strengthening to improve this imbalance (Stastny et al., 2018, 2014, 2016).

BP has been studied extensively; there have been kinematic and electromyography (EMG) analyses of prime movers and the supporting effects of stabilising muscles (Saeterbakken et al., 2017; Stastny et al., 2017; Van den Tillaar & Ettema, 2013). Increased muscle activation resulting from training has mostly been attributed to a combination of greater recruitment and a higher rate coding of stimulated motor units following training (Enoka & Duchateau, 2015; Vigotsky et al., 2017). The importance of pectoralis major (PM), the anterior deltoid (AD) and triceps brachii (TB) as prime movers in the flat bench press is in providing a propulsive force, stabilising the movement and overcoming the sticking region in successful lifts (Elliott et al., 1989; Moras et al., 2010; Stastny et al., 2017; Van den Tillaar & Saeterbakken, 2014; Van Den Tillaar & Saeterbakken, 2013; Van den Tillaar et al., 2012). However, there is little research indicating changes in muscle activity patterns during the bench press after resistance training for selective muscle groups. This knowledge would be very useful for exercise selection for training programmes aimed at increasing or optimising BP performance. On the other hand, there are numerous studies (Harøy et al., 2019; Jensen et al., 2014; Lehnert et al., 2017; Mjølsnes et al., 2004; Tyler et al., 2002) that successfully applied specific muscle-targeted training on weak muscle groups, such as the hamstrings and hip adductors. Although targeted training programmes were able to increase hamstring or hip adductor muscle strength (Jensen et al., 2014; Lehnert et al., 2017) and prevent injuries (Harøy et al., 2019; Mjølsnes et al., 2004), it remains unknown how targeted strengthening influences muscle activity patterns in agonist muscle groups.

The current resistance training approach considers complex exercises to be the main tool for improving muscle strength and performance, but isolated exercises are useful when certain muscle groups are weak (Giannakopoulos et al., 2004). In practice, complex exercises are combined with isolated exercises targeting weak muscle groups (Stastny et al., 2016), where the aim of this combination is to strengthen muscle patterns with increased stimulation of the weak parts of muscle chains. Although muscle force is not directly related to muscle activity, it is a relevant record of the motor unit activation level (Vigotsky et al., 2017); therefore, muscle weakness can be determined by the net force production of a single-joint maximum contraction (Stastny et al., 2018) or by a lack of muscle activity (Sole et al., 2011). This is related to the strategies of muscular activation patterns used by the central nervous system, in which the muscle length, joint angle, speed of contraction and muscle excitation are the key factors for maximum muscle force generation (Baechle & Earle, 2008). Changes in muscle activity as a result of a particular muscular weakness or fatigue can cause modifications in movement techniques, which might change movement control and the mechanical energy transmitted to joints and passive structures. Therefore, targeted resistance training can affect the relationships between the strength of particular muscle groups during maximal and submaximal performance and optimise the contribution of potentially weakened muscles.

Because the strengthening effect of targeted training on muscle activity in complex exercises has not been experimentally determined, the aim of the present study was to investigate changes in patterns of neuromuscular activity before and after a six-week period of targeted resistance training. We hypothesised that a six-week targeted strength training programme would change the pattern of neuromuscular activity during a bench press exercise and that the targeted muscle group would have increased activity.

Methods

Experimental approach

This intervention study was performed with a parallel-group, pre-post design, and the parallel groups were intentionally selected. The participants were familiarised with the testing and training protocols one week prior to the study. Then, they performed the isometric and dynamic BP protocols to identify muscle activity deficiencies, which were used for intentional assignment to one of three intervention groups. The groups performed targeted strengthening for the AD, PM or TB for six weeks, followed by post-intervention muscle deficiency identification and determination of the 1RM BP (Figure 1). The differences between the pre- and post-muscle activity deficiencies and 1RM BP were analysed by statistical methods. All measurements were performed in the Strength & Power Laboratory of the Jerzy Kukuczka Academy of Physical Education (Katowice, Poland), and the training sessions were conducted in the academy gym.

The warm-up before all pre-tests and post-tests consisted of general and specific parts. In the general part, the athletes exercised on a hand cycle ergometer for 5 min (at a heart rate of approximately 130 bpm) and performed several strength exercises that involved the upper and lower body without an external load (10 body-weight pull-ups, 15 push-ups, 10 split squats, and 10 bilateral squats). The specific part of the warm-up consisted of three bench press sets with a 2-min rest interval, and the load was adjusted to perform 15 repetitions at 40% of the 1RM, 10 repetitions at 60% of the 1RM and 5 repetitions at 70% of the 1RM. One week before the main experimental session, the bench press one repetition maximum (1RM) was determined for all participants.

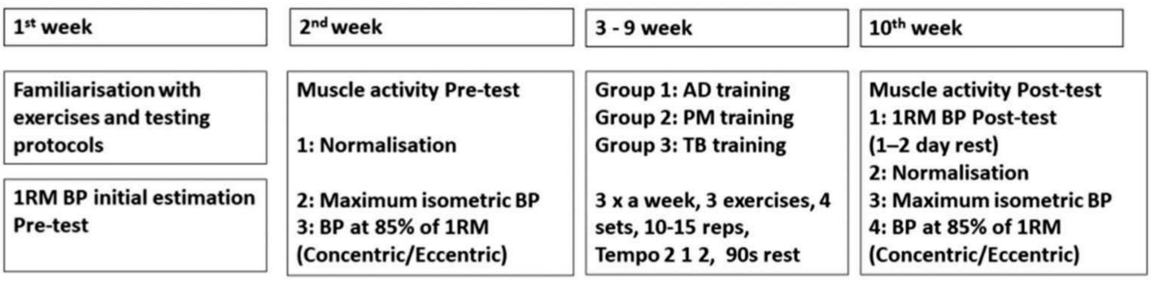

Figure 1. Scheme of measurements and trainings for the parallel groups, which underwent targeted training for different activity-deficient muscle groups.

RM = repetition maximum, BP = bench press, AD = anterior deltoid, TB = triceps brachii, long head, PM = pectoralis major, sternal portion.

Participants

The study included 27 men with at least 5 years of resistance training experience. The participants were familiar with the bench press technique described by the International Powerlifting Federation (IPF) and had a 1RM of 105.2 ± 27.9 kg; each participant lifted more than 120% of his body weight. The mean age, body mass and height were 26.7 ± 7.6 years (range 21–31), 87.3 ± 10.2 kg and 179.3 ± 11.2 cm, respectively.

The participants did not perform any resistance training for 72 hours prior to testing to avoid fatigue. The participants were informed verbally and in writing about the procedures, possible risks and benefits of the study, and they provided written consent before the start of the experiment. The study received the approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland (NRSA 404,054).

One repetition maximum bench press

The bench press 1RMs were performed with an Eleiko Olympic barbell (2.8-cm diameter, length 1.92 m) and on an Eleiko competition bench. Participants were instructed to self-select their optimal grip width, and all participants selected the maximum 81-cm distance. Body position was in accordance with IPF rules, i.e. the head, shoulders, and buttocks were in contact with the bench surface, and the feet were flat on the floor. Participants performed a bench press with a controlled 2-s eccentric contraction, a full stop in the bottom position touching the thorax, and a concentric contraction performed as fast as possible until full elbow extension was achieved. The chest touch was used while avoiding bouncing the barbell off the chest according to IPF rules. When the self-reported 1RM was successful, a trial with an additional load of 2.5–5 kg was performed (Van den Tillaar & Saeterbakken, 2014). When the initial trial was unsuccessful, the weight was decreased by 2.5–5 kg. A total of two or three trials were performed per participant.

Electromyography

An eight-channel Noraxon TeleMyo 2400 system (Noraxon USA Inc., Scottsdale, AZ, USA; 1500 Hz) was used for recording and analysing the biopotentials of the muscles. The activity was recorded bilaterally for three muscles: PM (the sternal portion), AD, and TB (the long head). The long head of the triceps was chosen according to previous research, where the activity of this head was identified as being common among main factors contributing to successful 1RM lifts during bench press (Maszczyk et al., 2014), and because the applied training intervention included exercises such as supine barbell triceps extension, which involves high activation of the TB long head (Wakahara et al., 2012). The sternal portions of the PM and the AD were selected according to their function as prime movers during bench press (Stastny et al., 2017) and their involvement in targeted exercises for PM, such as flyes (Reiser et al., 2017) and AD training, including front raises and lateral raises (Bagchi & Raizada, 2016; Botton et al., 2013). Before placing the 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, and the placement location was marked on the skin with a permanent marker. 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 of SENIAM (Hermens et al., 2000). The EMG signals were sampled at a rate of 1000 Hz. Signals were bandpass filtered with cut-off frequencies of 8 Hz and 450 Hz, after which the root-mean-square (RMS) was calculated. The grounding electrode was placed on the connection with the triceps brachii muscle on the olecranon. Electromyography was synchronised with a 2D video recording of the barbell track in the vertical plane (the camera was positioned horizontal to the bench) at 200 Hz and was used for identification of the eccentric and concentric parts of the movement. Before determination of the muscle activity deficiency, 2–3 s maximum voluntary contraction tests of static single-joint isometric activity in each muscle group were performed to normalise the electromyography recordings, according to the SENIAM procedure (Hermens et al., 2000). The peak values obtained during two maximum voluntary contractions (separated by a 2-min rest interval) were averaged and used to normalise muscle activity levels during bench press isometric and dynamic contractions.

Muscle activity determination

Muscle deficiency (i.e. lack of activity) was determined by the peak muscle activity level in the single-joint normalisation by SENIAM and by either a maximum isometric bench press test or a dynamic submaximal bench press, which should not be substantially different (Burden, 2010; Knudson & Johnston, 1993). The muscle group with the lowest percentage value during the isometric bench press (PM, AD, or TB) was considered the muscle with activation deficiency, and the concentric dynamic EMG value was used for confirmation of the muscle deficiency during the dynamic contraction. Moreover, the initial muscle activation level during the isometric and dynamic bench press was used as the pre-test activity value, and the same procedure was performed for the post-test EMG activity value after the resistance training programme. Participant grouping was performed according to the identified muscle activity deficiency. During the determination session, the participants performed two 4-s maximal isometric bench press repetitions with a load that prevented displacement of the barbell (200% 1RM). Each isometric test was performed with an angle of 90º between the arms and forearms (i.e. elbow flexion 90°) and with the upper arm perpendicular to the floor. The participant performed two maximal efforts with a 3-min rest interval, and the average of the two peak values for each muscle group was used for statistical analyses. Five minutes after completion of the isometric test, the participants performed 3 repetitions of the bench press with a load of 85% of their 1RM, and the peaks from all three repetitions were averaged. A load of 85% was determined for pre and post testing sessions separately.

Resistance training programmes

The training programme included 3 weekly sessions consisting of 3 exercises isolating particular muscle groups (PM, AD, TB), which were performed until concentric muscle failure in 4 sets of 10–15 repetitions at a movement tempo of 2 1 2. The rest intervals between sets and exercises were 90 s. The training intervention programme was scheduled for 6 weeks, considering the basic principles of resistance training periodicity. During the experimental training protocol, the athletes performed 3 training sessions per week, which included load progression in terms of resistance and the number of repetitions and sets. Three sets of a 4RM bench press were also performed once a week to maintain the proper movement pattern in this exercise and to prevent a decline in the 1RM bench press result. After completion of the 6-week training cycle, the participants followed the same test protocol as that performed at baseline.

The training exercises targeted at activating the AD muscle included the following: close-grip high row with barbell, dumbbell lateral raise, and dumbbell front raise, where an AD contribution is expected (Bagchi & Raizada, 2016; Botton et al., 2013). The training exercises directed at activating the PM muscle included bench flyes, machine chest flyes, and cable chest flyes (Reiser et al., 2017). To target the TB muscle, the athletes performed the following exercises: supine barbell triceps extension, high pulley cable triceps extension, and incline dumbbell triceps extension (kickback), where a TB long head contribution and shoulder stabilising requirements are expected (Rafiee et al., 2013; Soares et al., 2016; Wakahara et al., 2012). The Eleiko barbell (diameter: 2.8 cm; length: 1.92 m), Eleiko weight plates, and a professional Eleiko bench were used during training and testing.

Statistical analysis

The data were processed using Statistica software 13.4 (TIBCO software Inc. 2019, Palo Alto, CA, USA) with some R software integration, and the statistical significance was set at $p < 0.05$. The basic dataset was presented as the mean and confidence intervals in the tables and as the standard error in the figures. The reliability of the EMG measurement was estimated by the intraclass correlation coefficient across measurement repetitions in the measurement trials (two trials for the isometric EMG test and three repetitions for the dynamic EMG test). Two-way ANOVA for repeated measures was used to find differences between the pre- and post-values of the 1RM and peak muscle activities (activity MVIC x group x pre-test/post-test); the nonparametric effect size was determined with Hays ω^2, and Tukey's post hoc test was used. For ω^2, 0.10–0.29, 0.30–0.49 and > 0.50 were considered weak, moderate and strong associations, respectively (Hays, 1994).

Results

Of the 27 participants qualified for the experiment, 10 athletes showed the lowest activity in the TB muscles, 8 had the lowest activity in PM, and the remaining 9 athletes had the lowest muscle activity in the AD. Participants in each group progressively increased their training load in all exercises during the training intervention (supplementary material 1), which ensured the strength increase in the targeted muscle groups. All EMG measures had acceptable reliability (intraclass correlation 0.87–0.95). Changes in the peak activity of the prime movers during static and dynamic bench press testing in the experimental groups before and after 6 weeks of targeted resistance training are presented in Tables 1

Table 1. Prime movers muscle activity during isometric bench press before and after six weeks of targeted muscle strengthening of muscles with activity deficiency.

		Pre-test		Post-test	
Group	Muscle	Mean ± SD (%MVIC)	95% CI	Mean ± SD (%MVIC)	95% CI
Anterior deltoid training	AD*	60 ± 10	49–71	85 ± 15**	68–101
	PM	92 ± 14	77–106	88 ± 9	78–98
	TB	91 ± 10	80–101	90 ± 10	79–101
Pectoralis major training	AD	119 ± 10	107–130	104 ± 9†	95–114
	PM*	58 ± 8	49–67	76 ± 9**	66 – 85
	TB	83 ± 9	72–93	87 ± 9	78–97
Triceps brachii training	AD	99 ± 15	84–116	92 ± 10	81–103
	PM	100 ± 10	89–111	87 ± 9†	77–97
	TB*	79 ± 10	69–89	120 ± 19**	99–140

AD = anterior deltoid, PM = pectoralis major, TB = triceps brachii, SD = standard deviation, CI = confidence interval, * muscle group with initial muscle activity deficiency, **significant increase in comparison to pre-test $p < 0.05$. † significant decrease in comparison to pre-test $p < 0.05$. %MVIC = values are expressed as percentage of maximum isometric single joint contraction.

Table 2. Prime movers muscle activity during 85% repetition maximum bench press before and after six weeks of targeted muscle strengthening of muscles with activity deficiency.

		Pre-test		Post-test	
Group	Muscle	Mean ± SD (%MVIC)	95% CI	Mean ± SD (%MVIC)	95% CI
Anterior deltoid training	AD*	90 ± 9	81–98	101 ± 10**	90–112
	PM	115 ± 8	106–123	105 ± 8	97–113
	TB	105 ± 12	93–118	92 ± 9	82–101
Pectoralis major training	AD	105 ± 11	93–116	98 ± 9	88–108
	PM*	93 ± 10	83–103	100 ± 11**	89–111
	TB	105 ± 9	96–115	97 ± 9	88–106
Triceps brachii training	AD	93 ± 9	83–102	96 ± 9	86–105
	PM	111 ± 9	102–121	100 ± 9	90–109
	TB*	83 ± 8	74–93	100 ± 11**	89–111

AD = anterior deltoid, PM = pectoralis major, TB = triceps brachii, SD = standard deviation, CI = confidence interval, * muscle group with initial muscle activity deficiency, ** significant increase in comparison to pre-test $p < 0.05$. † significant decrease in comparison to pre-test $p < 0.05$. %MVIC = values are expressed as percentage of maximum isometric single joint contraction.

and 2. Repeated measures ANOVA showed that all three intervention groups had significantly increased bench press 1RM performance between the post-test compared to the pre-test ($F_{1, 20} = 6$, $p < 0.05$, $\omega^2 = 0.14$, Figure 2) and that the AD training group had significantly higher pre- and post-training 1RMs than the PM and TB training groups ($F_{1, 20} = 18.7$, $p < 0.001$, $\omega^2 = 0.45$) (Figure 2). However, the percentage change between the pre- and post-training 1RM values did not differ between the groups (AD increase 2.9 ± 2.1%, PM increase 2.8 ± 1.8%, TB increase 3.1 ± 3.8%).

Two-way repeated measures ANOVA showed differences in isometric bench press muscle activity among the intervention groups ($F_{4, 204} = 27$, $p < 0.001$, $\omega^2 = 0.33$), and the post hoc test showed that the AD training group had lower AD activity than the PM and TB training groups and that the TB training group had lower AD activity than the PM training group during the pre-test and post-test (Figure 3). The PM training group had lower PM activity than the AD and TB training groups during the pre-test and post-test, and the AD training group had lower PM activity than the TB training group during the

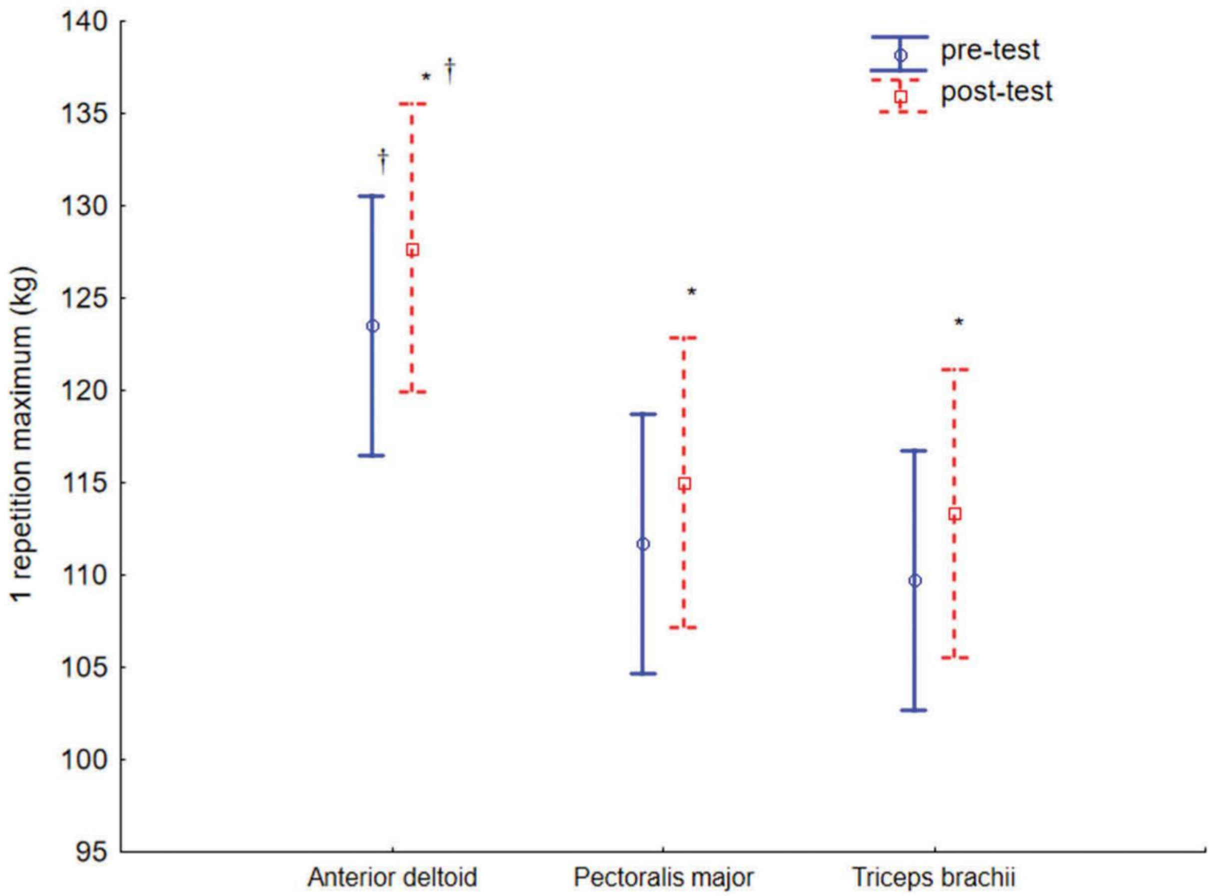

Figure 2. Changes in the one repetition maximum bench press before and after six weeks of targeted muscle strengthening for muscles with muscle activity deficiency.

Values are expressed in means and standard errors, * significant increase in comparison to the pre-test $p < 0.05$ for the same group, † different than other groups $p < 0.05$.

pre-test (Figure 3). The TB training group had lower TB activity than the AD training group during the pre-test and higher TB activity than the PM and AD training groups during the post-test (Figure 3). This result indicates that the AD and PM training groups did not have a change in deficient muscle group but that the TB training group had an increase in TB activity in comparison to the other groups.

Other differences were found between the pre-test and post-test isometric muscle activity in particular training groups ($F_{2,\ 60} = 10$, $p < 0.001$ $\omega^2 = 0.20$): AD training resulted in increased AD activity and decreased PM activity between pre-test and post-test; PM training increased PM activity and decreased TB activity between the pre-test and post-test; and TB training increased TB activity between the pre-test and post-test (Figure 3). These results mean that each type of training resulted in an increase in the targeted muscle activity and that the AD and PM training resulted in a decrease in the activity of muscle groups not targeted by the training intervention.

Two-way repeated measures ANOVA showed differences in 85% of 1RM bench press muscle activity among intervention groups ($F_{4,\ 204} = 42$, $p < 0.001$, $\omega^2 = 0.46$), and the post hoc test showed that the AD training group had lower AD activity than the PM and TB

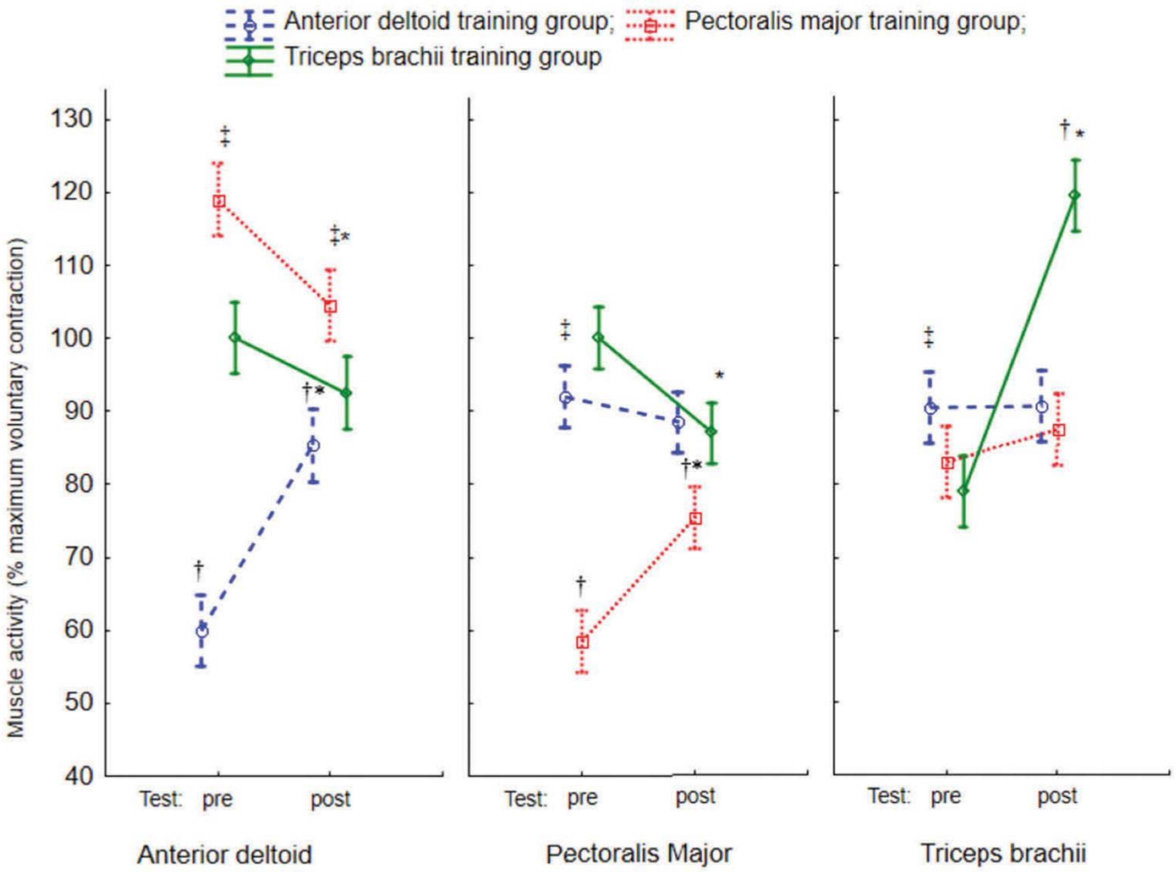

Figure 3. Changes in isometric bench press muscle activity before and after six weeks of targeted muscle strengthening for muscles with muscle activity deficiency.

* significant change in comparison to the pre-test $p < 0.05$ for the same group, † different than other groups $p < 0.05$, ‡ different than triceps brachii training group during the same period of testing (pre-test or post-test).

training groups and that the TB training group had lower AD activity than the PM training group during the pre-test (Figure 4). During the post-test, the AD training group had greater AD activity than the TB training group (Figure 4). The PM training group had lower PM activity than the AD and TB training groups during the pre-test, and the AD training group had greater PM activity than the TB and PM training groups during the post-test (Figure 4). The TB training group had lower TB activity than the AD and PM training groups during the pre-test, and the TB and PM trainings resulted in higher TB activity than the AD training during the post-test (Figure 4). This result indicates that the TB, AD and PM trainings changed the activity deficient in muscle group during dynamic contraction.

Differences in 85% of 1RM bench press activity were found between the pre-test and post-test in particular training groups ($F_{2, 60} = 8$, $p < 0.001$ $\omega^2 = 0.20$): AD training resulted in increased AD activity and decreased PM and TB activity between the pre-test and post-test; PM training increased PM activity and decreased TB and AD activity between the pre-test and post-test; and TB training increased TB activity and decreased PM activity between the pre-test and post-test (Figure 4). This result indicates that each training resulted in increased targeted muscle activity and decreased activity in other muscle groups.

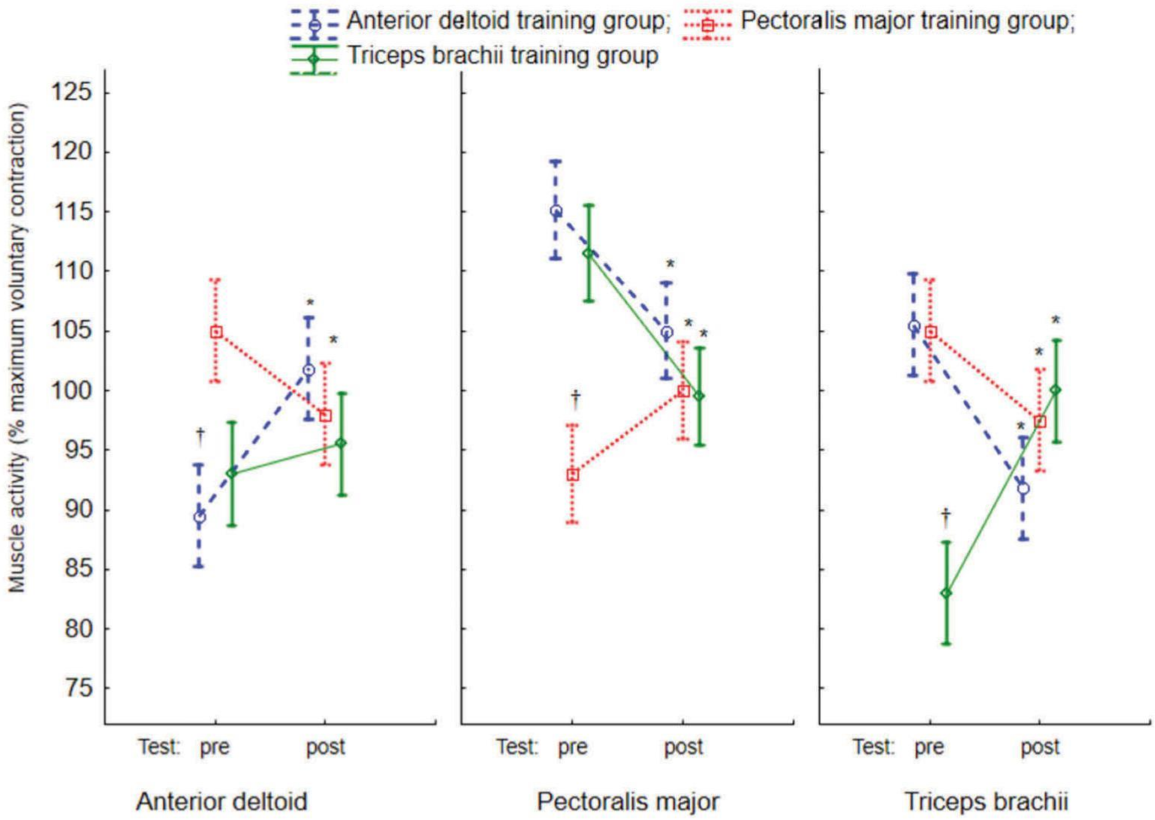

Figure 4. Changes in the 85% of the one repetition maximum bench press muscle activity before and after six weeks of targeted muscle strengthening for muscles with activity deficiency.

* significant change in comparison to the pre-test $p < 0.05$ for the same group, † different than other groups $p < 0.05$, ‡ different than triceps brachii training group during the same period of testing (pre-test or post-test).

Discussion and implications

The most important finding of this study is that the 6-week period of targeted resistance training affected the pattern of concentric and isometric muscular activity during BP, which increased the 1RM performance. Therefore, we can assume that identification of muscle activity deficiencies during single-joint maximum isometric contractions and complex movements might be a useful method for optimising exercise selection and identifying which specific prime movers should be trained. This finding is in accordance with previous findings that EMG and the load lifted increased after training programmes in elite weightlifters (Häkkinen et al., 1987) and adds the knowledge that such increases also occur in specific muscle-targeted training. Although resistance-trained athletes use specific recruitment patterns among synergists to ensure the required force for complex movements, regulating the strength of particular muscle groups can elicit adaptations in complex movement patterns (Enoka & Fuglevand, 2001).

Our finding that there is an increase in all activity-deficit prime mover activity after a selective 6-week targeted training may be associated with changes in tonic muscle control (Duchateau & Enoka, 2011), indicating that the central nervous system establishes a new movement pattern at submaximal intensity (85% of 1RM) for complex movement task-based inertial interactions between body segments. A previous study reported an increase in muscle activity during BP following acute increases in movement speed (Sakamoto & Sinclair, 2012), pre-exhaustion (Gentil et al., 2007; Golas et al., 2017), changes in stability requirements (Moras et al., 2010) and mental concentration focus (J. Calatayud et al., 2016, 2018) but not following interventions based on variable range-of-motion training (Clark et al., 2011) or elastic band push-up training (Calatayud et al., 2015). Since acute effects are related to fatigue or pre-activation mechanisms rather than changes or muscle activity patterns, we can conclude that our targeted muscle training can provide evidence-based muscle activity changes in prime movers during complex movements.

An increase in isometric and dynamic TB activity was found after the TB training programme, which should be highly recommended for practical use. The explanation for this result might be that TB plays an important role in maximum performance (Golas et al., 2017) and overcoming the sticking region (Van den Tillaar et al., 2012) during BP exercises. Another explanation might be that TB is a more distal extremity muscle group with a more isolated function than the AD and PM and thus might be more sensitive to targeted exercises. On the other hand, the lack of improvement in isometric AD and PM activity (along with the improvement in dynamic activity) might be related to the time necessary for a change in activity pattern, which might be difficult to attain due to the multivariate functions of the AD and PM and, in the case of PM, the large innervation area (Drake et al., 2016). Furthermore, PM is less frequently used in everyday activities than TB and the AD, which may have translated into a lack of application of PM in complex exercises.

The main limitations of our results are that we performed muscle deficiency training without a control group exercising no prime mover muscles (e.g. biceps), as we were not able to recruit one, and that there is general methodological error in EMG (Vigotsky et al., 2017). On the other hand, since we found the main results on the dynamic and isometric BP tests (Burden, 2010; Vigotsky et al., 2017), we can ignore the errors arising from dynamic EMG. Another limitation is the lack of isolated muscle strength measurements in our experiment, as we expected that targeted muscle training would increase the strength of the trained muscle group. However, the increased strength in trained muscle groups is documented for the training protocol in supplementary file 1. Our training programme also included one submaximal bench press session, which might contribute to the level of 1RM performance along with the targeted training. However, the 1RM bench press increase was considered to be due to the high volume of target exercises rather than 3 sets of complex movements per week. Taking the abovementioned limitations and our results together, future studies should focus on identifying whether some activity patterns can be considered optimal (e.g. the AD deficiency group had the highest 1RM) and how targeted or other training influences the relationship between muscle activity and single-joint net force or moment production (e.g. under isokinetic conditions).

The practical implication of our results is that exercises, including the following, can be selected to reduce TB activity deficiency: Supine barbell triceps extension, high pulley cable triceps extension, and incline dumbbell triceps extension. After application of these exercise programmes, practitioners should expect an increase in TB activity and exhaustion during bench pressing and probably during other upper limb presses, such as dumbbell chest press. When coaches apply targeted training to reduce PM and AD activity deficiency, they should expect an increase in the activity of these muscles but not that their activity would be dominant during BP after this intervention. Another implication is in the use of muscle activity deficiency during single-joint maximum isometric contractions and complex dynamic movements as a useful method for identifying which specific prime movers should be trained to change muscle activity patterns to potentially increase the 1RM performance.

Conclusion

Targeted muscle training is a useful method for reducing muscle activity deficiency, and it increases the maximum strength of complex exercise performance when applied in activity-deficient muscle groups. Strengthening an activity-deficient TB elicits changes in all prime movers and results in TB activity domination during the bench press. PM-targeted training seems to be less effective for PM muscle activity deficiency reduction than training for an activity-deficient AD or TB.

Disclosure statement

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Tyler, T. F., Nicholas, S. J., Campbell, R. J., Donellan, S., & McHugh, M. P. (2002). The effectiveness of a preseason exercise program to prevent adductor muscle strains in professional ice hockey players. *The American Journal of Sports Medicine*, *30*, 680–683. doi:10.1177/03635465020300050801

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6 PODSUMOWANIE

Aktywność mięśni znormalizowana w odniesieniu do maksymalnego potencjału w warunkach statycznych (%) pomogła ocenić wpływ wzrostu obciążenia zewnętrznego, na strukturę wewnętrzną wyciskania sztangi leżąc pomiędzy mężczyznami i kobietami. U obu płci wraz z obciążeniem zewnętrznym wzrasta aktywność w pracujących mięśniach. Występują różnice w aktywności mięśniowej związane z odmienną strukturą wewnętrzną ruchu pomiędzy mężczyznami i kobietami. Najważniejszą różnicą pomiędzy wyciskaniem sztangi leżąc pomiędzy kobietami i mężczyznami, jest odmienna aktywność mięśnia trójgłowego ramienia (głowa długa). U mężczyzn aktywność ta znacząco rośnie, natomiast u kobiet nie odnotowano istotnego statystycznie wzrostu aktywności mięśnia trójgłowego ramienia pod wpływem wzrastającego obciążenia. Różnice te, mogą wynikać z niższego poziomu siły kończyn górnych u kobiet związanych z mniejszą masa mięśniową. (Gołaś i wsp. 2018).

Elektromiografia powierzchniowa pozwala ocenić nerwowo-mięśniową kontrolę aktywności określonych grup mięśniowych. Wielostawowe ćwiczenia oporowe, realizowane z obciążeniem zewnętrznym umiarkowanym, do upadku mięśniowego, mogą prowadzić do ostrego zmęczenia zarówno centralnego, jak i obwodowego układu nerwowego (Zając i wsp. 2015). Można stwierdzić, że brak możliwości zwiększenia napięcia mięśni w kolejnych seriach oraz ograniczona liczba powtórzeń wykonanych w ostatniej (10) serii związana jest z ostrym zmęczeniem CUN i kumulacją ubocznych produktów metabolizmu wysiłkowego (Zając i wsp. 2015).

Analiza wzorca aktywności mięśniowej jest coraz częściej wykorzystywana w celu poprawy skuteczności zaplanowanego programu treningu oporowego, np. w celu poprawy efektywności wyciskania sztangi leżąc. (Gołaś i wsp. 2018; Statsny i wsp. 2017; Vigotsky i wsp. 2017). Niniejsze badania wskazują, iż aktywność mięśnia trójgłowego ramienia (głowy długiej) uległa istotnemu wzrostowi pod wpływem 6 tygodniowego, ukierunkowanego treningu oporowego. Z badań wynika, iż mięsień naramienny oraz mięsień piersiowy większy w mniejszym stopniu adaptuje się do zrealizowanego bodźca treningowego. Dodatkowo okres 6 tygodni zastosowany w badaniach mógł być zbyt krótki do wystąpienia bardziej istotnych zmian w strukturze wewnętrznej ruchu. Celem badania struktury wewnętrznej ruchu jest identyfikacja deficytów w aktywacji mięśni lub grup mięśniowych biorących udział w pokonywaniu oporu zewnętrznego (Van den Tillar i wsp. 2012; Maszczyk i wsp. 2016), co może pomóc poprawić efektywność, pokonać stagnację treningową lub zapobiec urazom (Serner i wsp. 2014). Jeżeli mięsień wykazuje niższy poziom aktywacji, należy zastosować ukierunkowane treningi oporowe, które pozwolą wzmocnić najsłabsze grupy mięśniowe (Statsny i wsp. 2014; 2017; 2018).

Istota elektromiografii powierzchniowej w sporcie jest zagadnieniem poruszanym od dłuższego czasu. Szczególnie ważna jest ona w aspekcie procesu treningu sportowego. W przedstawionym cyklu prac, które stanowią osiągniecie naukowe, głównym problemem badawczym jest analiza wzorca aktywności wiodących grup mięśniowych, biorących udział w ćwiczeniu oporowym, jakim jest, wyciskanie sztangi leżąc na ławce płaskiej. Wyniki uzyskane z powyższych analiz umożliwią pełniejszy opis czynności ruchowej, jaką jest wyciskanie sztangi leżąc na ławce płaskiej, a tym samym pozwala zwiększyć efektywność procesu treningowego, zarówno osób doświadczonich, jak i początkujących w tym ćwiczeniu, a także w tej dyscyplinie sportu.

7 SUMMARY

Muscle activity normalized with respect to maximal potential under static conditions (%) helped fully evaluate the effects of increased load on the internal structure of flat bench press between men and women. Activity in working muscles increases with external load in both males and females. There are differences in muscle activity associated with the different internal structure of the movement between men and women. The most important difference between flat bench press in both sexes is the different activity of the triceps brachii muscle (long head). This activity increases significantly in men, while in women there was no statistically significant increase in the activity of the triceps brachii muscle under the influence of increasing external loads. The differences in electromyography changes with progressive loads between male and female athletes may result from the lower level of strength of the upper limbs in women caused by lower activity of the triceps brachii muscle compared to men (Gołaś et al. 2018).

Electromyography allows the assessment of neuromuscular control of the activity of specific muscle groups. 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. (Zając et al. 2015). It can be concluded, than the inability to increase tension in successive repetitions and the limited number of repetitions performed in the last (10) set, can be explained by fatigue of the CNS and accumulation of metabolism by-products (Zając et al. 2015).

Analysis muscle activity patterns is widely used to improve resistance training effectiveness, e.g. to improve bench press (BP) performance (Gołaś et al. 2018, Stastny et al., 2017, Vigotsky et al. 2017). This result indicate, that triceps brachii muscle activity (long head) significantly increased in the influence of 6 weeks of targeted resistance training Research shows that the deltoid muscle and pectoralis major muscle adapt to the training stimulus to a lesser extent. Additionally, the 6-week period used in this research could be too short for more significant changes in the internal structure. The purpose of such analyses is to identify possible deficiencies in muscle activation or the most active muscle group when overcoming external resistance (Maszczyk et al. 2016, Van den Tillaar et al. 2012), which might help to improve performance, overcome training stagnation or prevent injury (Serner et al. 2014). If a lack of muscle activation is found, targeted muscle strength training should be used to improve the weak les muscle group (Stastny et al. 2018, 2014, 2016).

The essence of electromyography in sport has been an issue raised for a long time. It is particularly important in the aspect of the sport training process. In the presented series of research that constitute scientific achievement, the main research problem is the analysis of the activity pattern of the prime movers in the resistance exercise, which is flat bench press. The results obtained from the above analyzes will allow a more complete description of the physical activity, which is flat bench press, and therefore to increase the efficiency of the training process, both experienced and beginners in this exercise and in this sport.

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32. Stastny P, Lehnert M, and Tufano JJ. Muscle Imbalances: Testing and Training Functional Eccentric Hamstring Strength in Athletic Populations. *JoVE*. 2018; e57508.

33. Katarzyna Strońska, Marta Trebert, Artur Gołaś, Adam Maszczyk, Adam Zając. Changes in EMG activity of the prime movers during 10 sets of the flat bench press performed to concentric failure**.** *Baltic Journal of Health and Physical Activity.* 2018; Vol. 10, nr 1, s. 22-29.

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9 POZOSTAŁE OSIĄGNIĘCIA NAUKOWE

9.1 Publikacje

Stanowią część dorobku naukowego doktoranta, niewchodzącą w skład monotematycznego cyklu publikacji.

- Artur Gołaś, Miłosz Drozd, Michał Krzysztofik, Katarzyna **Strońska**, Paulina Bojacz, Marcin Żak, Katarzyna Pajerska. Changes in the internal movement structure during the push and paddle phases in Olympic national team lugers. *Trends in Sport Sciences*. 2016, 23:2, 89-94.
  [MNiSW = 9 pkt.]
- **Katarzyna Strońska,** Paulina Bojacz, Artur Gołaś, Adam Maszczyk, Adam Zając, Petr Stastny. Muscle activity during the incline shoulder press in relation to the exercise intensity. *Acta Gymnica*. 2018, 48(4):141-146.
  [MNiSW = 9 pkt.]
- Artur Gołaś, **Katarzyna Strońska**, Michał Krzysztofik, Adam Maszczyk, Petr Stastny, Adam Zając. The influence of rest interval on total training load during 10 sets of the bench press exercise performed to concentric failure. *Medicina Dello Sport*.
  [IF = 0,172, MNiSW = 15 pkt.]
- Jakub Jarosz, Artur Gołaś, Michał Krzysztofik, Patryk Matykiewicz, **Katarzyna Strońska**, Adam Zając, Adam Maszczyk. Changes in Muscle Pattern Activity during the Asymmetric Flat Bench Press (Offset Training). *International Journal of Environmental Research and Public Health.* **[IF=2.468, MNISW=70 pkt.]**

9.2 Konferencje naukowe

- II Międzynarodowa Konferencja Naukowa: Motoryczność Sportowa – Założenia Teoretyczne i Implikacje Praktyczne organizowaną przez Akademię Wychowania Fizycznego w Krakowie. Kraków, 21-23.09.2017.
- II Ogólnopolska Konferencja Doktorantów oraz Studenckich Kół Naukowych: Nauka w Służbie Kultury Fizycznej organizowaną przez Akademię Wychowania Fizycznego w Katowicach. Brenna, 25-26.05.2017.
- XVI Ogólnopolska Konferencja Doktorantów oraz Studenckich Kół Naukowych: Nauka w Służbie Kultury Fizycznej organizowaną przez Akademię Wychowania Fizycznego w Katowicach. Brenna, 10-11.05.2018.
- I Międzynarodowa Konferencja „Sport – Peace Massage" organizowaną przez Benha University Faculty of Physical Education I Akademię Wychowania Fizycznego w Katowicach w dniach. Egipt, Sharm El Sheikh, 11-13 kwiecień 2018.
- Ogólnopolska Konferencja Doktorantów oraz Studenckich Kół Naukowych: Nauka w Służbie Kultury Fizycznej organizowaną przez Akademię Wychowania Fizycznego w Katowicach. Katowice, 06.06.2019.

9.3 Załącznik 3

Bibliografia Dorobku Pracowników za okres od 2016 do 2020

I - Informacje o publikacji P - Punktacja Σ - Suma punktów

Wyszukiwanie pracownika (szeregowanie alfabetyczne wg typu publikacji):

Strońska, Katarzyna

∑(IF): 6,777; ∑(w roku publikacji): 200,00

Liczba odpowiedzi = 7

Artykuły w czasopismach spoza list MNiSW (2017-2020)

∑(IF): 0,000; ∑(w roku publikacji): 5,00

Liczba odpowiedzi = 1

1. Muscle activity during the incline shoulder press in relation to the exercise intensity / Katarzyna Strońska, Paulina Bojacz, Artur Gołaś, Adam Maszczyk, Adam Zając, Petr Stastny.// Acta Gymnica [formerly Acta Universitatis Palackianae Olomucensis. Gymnica] Vol. 48, nr 4 (2018), s. 141-146 [DOI: 10.5507/ag.2018.019].

P(IF): 0,000; P(w roku publikacji): 5,00

Artykuły w czasopismach z listy "A" MNiSW 2013-2018 oraz z listy MNiSW 2019-2020

∑(IF): 6,777; ∑(w roku publikacji): 175,00

Liczba odpowiedzi = 4

1. Changes in Muscle Pattern Activity during the Asymmetric Flat Bench Press (Offset Training) / Jakub Jarosz, Artur Gołaś, Michał Krzysztofik, Patryk Matykiewicz, Katarzyna Strońska, Adam Zając, Adam Maszczyk.// International Journal of Environmental Research and Public Health Vol. 17, nr 11 (2020), s. 1-9 [DOI: 10.3390/ijerph17113912].

P(IF): 2,468; P(w roku publikacji): 70,00

2. The effect of targeted resistance training on bench press performance and the alternation of prime mover muscle activation patterns / Katarzyna Strońska, Artur Gołaś, Michał Wilk, Adam Zając, Adam Maszczyk, Petr Stastny.// Sports Biomechanics 2020, s. ? [DOI: 10.1080/ 1476-3141].

P(IF): 1,714; P(w roku publikacji): 70,00

3. The influence of rest interval on total training load during 10 sets of the bench press exercise performed to concentric failure / Artur Gołaś, Katarzyna Strońska, Michał Krzysztofik, Adam Maszczyk 10%, Petr Stastny, Adam Zając.// MEDICINA DELLO SPORT Vol. 72, nr 2 (2019), s. 181-90 [DOI: 10.23736/S0025-7826.19.03445-8].

P(IF): 0,393; P(w roku publikacji): 20,00

4. Muscular activity patterns of female and male athletes during the flat bench press / Artur Gołaś, Adam Maszczyk, Michał Wilk, Petr Stastny, Katarzyna Strońska, Marcin Studencki, Adam Zając.// BIOLOGY OF SPORT Vol. 35, nr 2 (2018), s. 175-179 [DOI: 10.5114/biolsport.2018.74193].

P(IF): 2,202; P(w roku publikacji): 15,00

Artykuły w czasopismach z listy "B" MNiSW 2013-2018 oraz z listy MNiSW 2019-2020

∑(IF): 0,000; ∑(w roku publikacji): 20,00

Liczba odpowiedzi = 2

1. Changes in EMG activity of the prime movers during 10 sets of the flat bench press performed to concentric failure / Katarzyna Strońska, Marta Trebert, Artur Gołaś, Adam Maszczyk, Adam Zając.// Baltic Journal of Health and Physical

Wyszukiwanie pracownika (szeregowanie alfabetyczne wg typu publikacji):

Activity Vol. 10, nr 1 (2018), s. 22-29 [DOI: 10.29359/BJHPA.10.1.02].

P(IF): 0,000; P(w roku publikacji): 11,00

2. Changes in the internal movement structure during the push and paddle phases in Olympic national team lugers / Artur Gołaś, Miłosz Drozd, Michał Krzysztofik, Katarzyna Strońska, Paulina Bojacz, Marcin Żak, Katarzyna Pajerska.// Trends in Sport Sciences Vol. 23, nr 2 (2016), s. 89-94.

P(IF): 0,000; P(w roku publikacji): 9,00

Liczba wszystkich publikacji: 7

9.4 Załącznik 4

Biblioteka AWF Katowice | Katowice, dn. 18.06.2020

10:21

Dorobek pracowników wg klasyfikacji za okres od 2016 do 2020 (wg roku)

Strońska, Katarzyna

Publikacje niesklasyfikowane

2017

1. II Międzynarodowa Konferencja Naukowa : Motoryczność sportowa - założenia teoretyczne i implikacje praktyczne. - Kraków : AWF, 21-23.09.2017.
Adnotacja:
Miłosz Drozd, Monika Nawrocka, Aleksandra Filip, Barbara Koteja, Roksana Krosta, Katarzyna Strońska, Michał Krzysztofik : "Models of elite soccer teams using speed abilities development index".

2. Ogólnopolska Konferencja Doktorantów oraz Studenckich Kół Naukowych : Nauka w Służbie Kultury Fizycznej. - Brenna : AWF im. J. Kukuczki w Katowicach, 25-26.05.2017.
Adnotacja:
Katarzyna Strońska : Zmiana wzorca aktywności mięśniowej w wyciskaniu sztangi leżąc do niewydolności mięśniowej.

2018

1. First International Conference Sport – Peace Message. - Sharm El Sheikh [Egyp] : Benha University Faculty of Physical Education; AWF im. J. Kukuczki w Katowicach, 11-13.04.2018.
Adnotacja:
Referaty.Katarzyna Strońska, Karolina Daros: Neuromuscular control during the bench press movement in female and male athletes.

Karolina Daros, Katarzyna Strońska: EEG Biofeedback training of Attentional Processing in Judo Athletes.

2. XVI Ogólnopolska Konferencja Doktorantów oraz Studenckich Kół Naukowych : Nauka w służbie kultury fizycznej. - Brenna : Kierownictwo Studiów Doktoranckich, Uczelniana Rada Samorządu Doktorantów Akademii Wychowania Fizycznego im. Jerzego Kukuczki w Katowicach, 10-11.05.2018.
Adnotacja:
Referaty.Katarzyna Strońska, Paulina Bojacz, Mateusz Halz: Analiza wzorca aktywności mięśni obręczy barkowej w zależności od wielkości obciążenia.

2019

1. Ogólnopolska Konferencja Doktorantów oraz Studenckich Kół Naukowych AWF Katowice. - Katowice : AWF im. J. Kukuczki w Katowicach, 06.06.2019.
Adnotacja:
Referaty.Katarzyna Strońska: Zmiana wzorca aktywności mięśniowej obręczy barkowej pod wpływem 6 tygodniowego ukierunkowanego treningu siły mięśniowej.

Liczba wszystkich publikacji: 5