Accepted Article

J Musculoskelet Neuronal Interact 2024

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

Neuromuscular Repatterning of the Pectoralis Major During the Bench Press Exercise Following a 10-week Targeted Resistance Training Intervention

Katarzyna Stronska-Garbien, Artur Golas, Robert Roczniok, Artur Terbalyan, Milosz Drozd

Department of Sports Training, Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

Abstract

Objective: The bench press is a resistance training exercise that targets several upper body muscles, including the pectoralis major (PM), anterior deltoid (AD), and triceps brachii (TB). The purpose of this study was to influence the PM activity pattern during the bench press after a 10-week targeted resistance training intervention. **Methods**: Sixteen men with significant experience in strength training participated in this study. They were divided into two groups: experimental and control. The experimental group underwent targeted training of PM and bench press, while the control group only did bench press. Electromyography (EMG) was used to assess muscle activity before and after the intervention. **Results**: The experimental group had a significant increase in PM activity after the intervention ($p=0.0002$; $ES=2.6$), while the control group did not show any significant change ($p=0.14$). The activity of AD and TB remained relatively stable across both groups and time points. **Conclusions**: These findings indicate that focused resistance training can improve PM involvement in the bench press, potentially optimizing muscle excitation patterns and performance.

Keywords: Deltoid Anterior, Electromyography, Neuromuscular Capacity, Strength Training, Triceps Brachii

Introduction

The bench press (BP) is a widely known resistance exercise that is considered one of the best for improving upper body strength and power[1]. Furthermore, it is a powerlifting discipline that hosts World and European championships[2-4], as well as several other authors[5] have confirmed that four muscle groups are primarily activated during this exercise: the pectoralis major (PM), the anterior deltoid (AD), the long (TBLong) and lateral (TBLat) head of the triceps brachii.

The crucial aspect of mastering any movement is to reprogram the central nervous system to educate the neuromuscular system appropriate mechanics while eliminating faulty recruitment patterns. This requires proper execution combined with frequent practice to consistently develop the appropriate neural pathways and motor patterns. The principle underlying motor learning and motor control is neuromuscular plasticity. This refers to the fact that the central nervous system (CNS) is highly pliable and adaptive to movement patterns performed during training. In simple terms, the body will gradually adjust and change its mechanics based on movement patterns grooved into the CNS by specific training techniques[6].

The aim of resistance training is to improve the ability of a certain muscle or muscle group to generate force under specific conditions. Systematic resistance training results in increased muscle mass, strength, and size[7]. Westcott and Wayne[8] demonstrated the benefits of resistance training on mental health, including reducing depressive symptoms, increasing psychological and physical self-esteem, and improving cognitive abilities[8]. Traditionally, strength training is performed with fixed-resistance equipment, such as free weights. However, recent literature suggests that variable resistance is a beneficial alternative to constant resistance

The authors have no conflict of interest.

Corresponding author: Artur Terbalyan, Department of Sports Training, Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Mikołowska st. 72A, 40-065 Katowice, Poland
E-mail: a.terbalyan@awf.katowice.pl

Edited by: G. Lyritis
Accepted 22 April 2024

during exercise[9]. For instance, Aboodarda et al.[10] and Israetel et al.[11] demonstrated that variable resistance increased agonist muscle excitation compared to constant resistance. However, this difference was only observed in the parts of the movement where variable resistance was greatest. Dunnick et al.[12] investigated the effect of an unstable external load on pectoralis muscle activity. They showed no significant differences in the eccentric phase, while the unstable load increased pectoral muscle activity during the concentric phase compared to performing the exercise under stable conditions.

The width of the barbell grip can also affect the change in muscle activity. Lehman et al.[13] and Barnett et al.[14] found that a wider grip resulted in greater activity of the pectoralis major muscle. Meanwhile, a study by Mausehund et al.[15] showed that a narrow grip resulted in greater activity in the triceps brachii and anterior deltoid compared to a wider grip. Furthermore, research has shown that a wider grip results in an increased external load due to the shorter vertical travel of the barbell[16,17]. Additionally, the angle of the bench may also affect the muscle activity of the pectoral girdle, as suggested by Stastny et al.[3]. Moreover, there are EMG differences between different variations of the same exercise[18] that can be also modulated by fatigue[19]. This can lead to selective excitation of different parts of the muscle, resulting in an increased number and frequency of recruited motor units. Fleck and Krahmer[20] suggest that targeted training and increased frequency of excitation lead to hypertrophy in different areas of the muscle. Barnett et al.[14] demonstrated greater overall excitation of the pectoral muscle during conventional BP. According to Egger[21], an incline bench angle activates the clavicular part of the pectoral muscle more, while decline bench press increases excitation of the sternocostal part of the muscle, as noted by Glass and Armstrong[22] and Coratella et al.[23]. However, Jagessar et al.[24] arrived at a different conclusion. Their study found no statistically significant differences in pectoral muscle activity among the various BP techniques, except for the lower region of the muscle in the incline BP, which was significantly lower compared to conventional and decline BP.

Research indicates that an increase in external load significantly increases muscle activity[25] in both novice and experienced athletes[26]. Muscle activity is also dependent on the type of muscle contraction, the exercise being performed as well as resistance training experience[27]. excitation of motor units varies between beginners and advanced individuals. For example, Saeterbakken et al.[27] proved that there are differences in the activity of the muscles studied in these training groups.

The literature describes the changes in muscle activity patterns quite well[3,25]. However, there is a lack of data on the changing of the activity pattern during the long-term training intervention. Specifically, there is a need to evaluate the least active muscle groups and the reduction of activity in the most active ones during resistance training. Numerous studies have shown that muscle function can be improved through corrective exercise strategies that alter movement patterns and characteristics. These strategies have been documented to be effective in practical applications as well.

Studies have confirmed the beneficial effect of targeted resistance training on the least active muscle group[27,29,30,31]. However, there is a lack of information regarding the effect of long-term targeted training on the engagement of selected muscle groups. The objective of this study was to examine the impact of a 10-week targeted resistance training program on the activity of the pectoralis major muscle during the bench press exercise.

Materials and Methods

Participants

Sixteen men with at least 5 years of strength training experience participated in the study. The selection process was deliberate. Each subject's BP technique was at a good level, and their one repetition maximum (1RM) was 100 ± 35 kg. The mean age, weight, and height were 27 ± 7.6 years, 87.3 ± 10.2 kg, and 179.3 ± 11.2 cm, respectively. The participants abstained from all forms of resistance training for 72 hours prior to the experiment in order to avoid fatigue.

Study design

In this study we analysed muscle activity in two groups of eight subjects: an experimental group and a control group. We evaluated muscle activity through EMG (electromyography) before and after 10 weeks of targeted resistance training of the pectoralis major. Participants were familiarized with the study protocol one week before the start of the study and determined their 1RM value according to the protocol of Saeterbakken et al.[27]. During the first day of the experiment, the participants underwent a BP protocol and isometric MVC contractions to determine the activity pattern of the pectoral girdle muscles. To determine sample size, a power analysis for a repeated measures ANOVA was performed using G*Power 3.1.6. Based on effect sizes reported in comparable studies the analysis indicated that a minimum of 16 participants would be required for an α of 0.05 and a power of 0.80. The 16 participants were randomly divided into two groups: experimental and control. Over the course of 10 weeks, the experimental group (8 subjects) performed targeted training of the pectoralis major (PM) and BP training, while the control group (8 subjects) performed BP training only. All the measurements were performed in the Strength and Power Laboratory of AWF Katowice. The warm-up before and after 10 weeks of targeted resistance training consisted of a general and a specific part. In the first part, the subjects exercised on a hand ergometer for 5 minutes (with a heart rate of about 130 beats per minute), then they performed several strength exercises without external load, which included the upper and lower body (push-ups, single leg hip-bridges, dead bugs). The specific part consisted of 3 sets of the BP with a load that allowed them to perform 15, 10, and 5 repetitions[32].

On the first day of the experiment, the peak activity levels of

Table 1. Basic descriptive statistics for analysed variables.

Group		M	CI -95%	CI 95%	Me	Min	Max	SD	P^a S-W
E	PMR -before	69,58	64,64	74,53	71,00	56,00	81,00	7,79	**0,76**
	PMR - after	91,49	86,36	96,62	94,43	73,72	103,10	8,07	0,14
C	PMR -before	67,75	63,51	71,99	68,50	57,00	79,00	6,68	0,25
	PMR - after	72,00	67,65	76,35	72,00	61,00	83,00	6,85	**0,63**
E	ADR -before	84,14	78,25	90,04	84,90	68,97	99,48	9,27	**0,96**
	ADR - after	80,92	76,04	85,79	81,50	71,00	93,00	7,67	0,37
C	ADR -before	82,33	78,35	86,32	84,00	71,00	91,00	6,27	0,25
	ADR - after	84,58	80,63	88,53	85,00	71,00	93,00	6,22	**0,56**
E	TBR -before	88,25	80,19	96,31	94,06	67,18	102,15	12,68	0,07
	TBR - after	84,92	80,48	89,36	85,50	75,00	96,00	6,99	**0,69**
C	TBR -before	84,67	79,19	90,14	88,00	69,00	94,00	8,62	0,11
	TBR - after	87,37	82,30	92,44	90,00	75,00	96,00	7,98	0,06

M- mean; Me-median, SD – standard deviation, CI95% - confidence interval for the mean, p S-W - Shapiro-Wilk test probability for normality of distribution. E – experimental group, C – control. PMR – pectoralis major right activity, ADR – anterior deltoid right activity, TBR – triceps brachii right activity. Significant p-values (>0,05) presented in bold for: aShapiro-Wilk test probability for normality of distribution. Value of each muscles' activity estimated relative to MVC (%).

the 3 muscles tested were examined for the right upper limb: pectoralis major right (PMR), anterior deltoid right (ADR) and triceps brachii longus right (TBR). For all subjects, the right limb was the dominant side. To normalize the results, the subjects performed two maximum 4-second MVC isometric presses for each muscle separately (PM, AD, TBLong) and for all muscles together, with a load that did not allow the barbell to move (200% of 1RM). The angle between the arm and forearm was 90° [33]. The average of the two peaks (PEAK) for each of the aforementioned muscles was used for statistical analysis of MVC. Ten minutes after completing the isometric test, participants performed 1 repetition of the BP with a load of 85% 1RM. The same procedure was performed after 10 weeks of targeted training of the pectoralis major muscle for both the experimental and control groups.

Training program

The study group underwent a 10-week training program for the pectoralis major. The program consisted of three single joint exercises, each performed in four sets to concentric failure with 10-15 repetitions. The rest interval between sets was 90 seconds. Load progression was set at 1.5-2.5% of 1RM. During the first training session, the 1RM load was determined for each exercise in each participant. During the experiment, the subjects completed a total of 30 training sessions, with each subject completing 3 sessions per week. Additionally, the subjects performed bench press training once a week to maintain the correct movement pattern of this complex exercise. The exercises for the targeted training sessions were selected from the Delavier's Atlas of Strength Training[34] and included Machine Chest Flyes, Dumbbell flyes, and Cable Chest Flyes.

Both the experimental and control groups underwent bench press training consisting of 5 sets of 8-12 repetitions with a load of approximately 75% of 1RM. Load progression was set at 2.5 kg per week.

Electromyography

A wireless eight-channel Noraxon TeleMyo system (Noraxon USA Inc., Scottsdale, AZ; 1500Hz) was used to record and analyse biopotentials from the muscles. Gel surface electrodes were placed on the skin surface along the course of the muscle fibers, following the SENIAM procedure[35]. A reference electrode was placed on the clavicle. The skin was properly prepared for the test by skin abrasion with sandpaper, shaving and cleaning with alcohol. Muscle activity levels of PM, AD, and TB were analysed for both the right and left upper limbs using a filming method to identify movement onset and termination on of the underlying muscle fiber, according to the recommendations of SENIAM[35]. The EMG signals will be sampled at a rate of 1000 Hz. Signals were bandpass filtered with a cut-off frequency of 8 Hz and 450 Hz, after which the root-mean-square (RMS) was calculated. Electromyography was synchronized with a 2D video recording of the barbell track in the vertical plane at 200 Hz and was used for identification of the eccentric and concentric part of movement. Before determination of the muscle activity deficiency, 2-3 s maximum voluntary contraction tests of the static isometric activity of each muscle group will be performed to normalize the electromyography recordings according to the SENIAM[35] procedure.

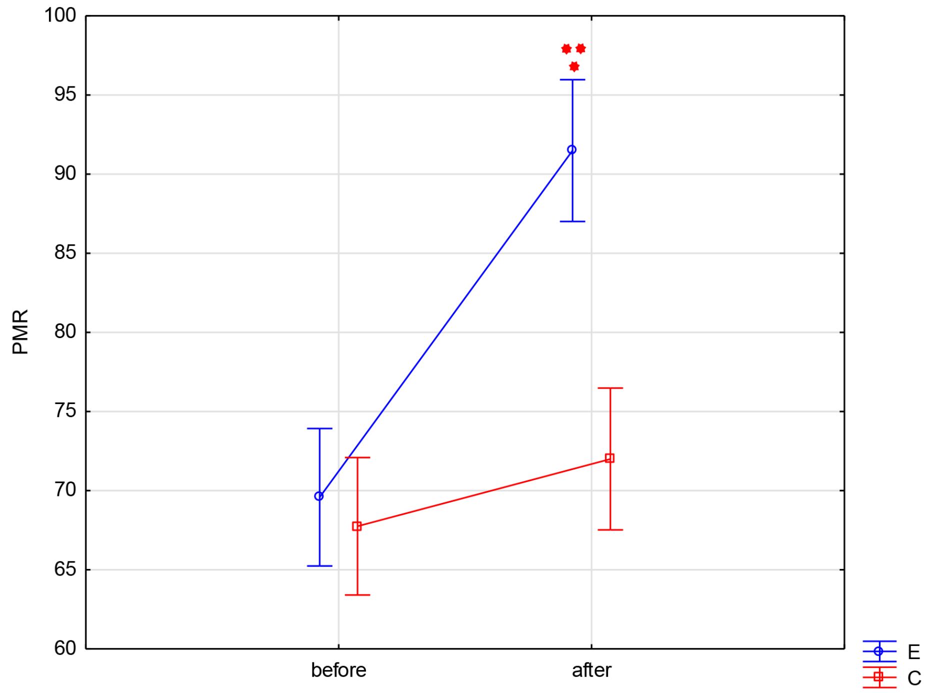

Figure 1. Comparison of mean values and confidence intervals for the PMR variable (pectoralis major right activity presented as % of MVC) by group. *significant change in comparison to the pre-test p<0.05 for the same group, ** intergroup difference p<0.05 for repeated-measures ANOVA.

Statistical analysis

Statistical analyses were performed using Statistica 13.1. The results are presented as means with standard deviations, standard errors, and 95% confidence intervals. Normality, homogeneity, and sphericity of the sample data variances were verified using the Shapiro-Wilk, Levene's, and Mauchly's tests, respectively. Differences between the considered variables were compared using repeated-measures ANOVA. In case of a significant main effect, Tukey's post hoc test was used for post hoc comparisons. The strength of the association in the analysis of variance was calculated using η2. The statistical significance for the differences between types of loads and muscle sides was set at $p<0.05$. Effect sizes (Cohen's d) were also calculated and interpreted as large for d > 0.8, moderate for 0.8>d>0.5, and small for d<0.5[36].

Results

Analysis of the results in Table 1 led to the conclusion that there was no evidence to reject the null hypothesis of normality of the distribution of the analysed variables. Therefore, parametric analysis of variance with repeated measures were used.

Significant differences were found for the main effects of the PMR variable: Group F=15.64; p=0.00067; η2=0.42; pre-post F=95.76; p<0.0001; η2=0.81, as well as for the interaction between main effects group*pre-post F=43.63; p<0.0001; η2=0.66. Further analyses were conducted using Tukey's post-hoc multiple comparisons tests to determine between which groups there were significant differences. The experimental group showed a statistically significant increase in mean PMR score after training (Mpre=69.58; Mpost=91.49; p=0.0002; d=2.76). However, there were no significant differences before and after the training intervention in the control group (p=0.14), and no significant differences between the groups in the results before the start of the experiment (p=0.92). Significant differences were observed in the results after the training intervention in the experimental group. The mean PMR activity in the experimental group was statistically higher after targeted training (p=0.0002; d=2.6). These results are supported by the accompanying figure.

The analysis of the results for the ADR variable led to the conclusion that no significant differences were found for the main effects of group (F=0.11; p=0.75) and pre-post (F=0.19; p=0.67). However, for the interaction group*pre-post, the analysis of variance allowed the rejection of the null hypothesis of no differences (F=5.98; p=0.023; η2=0.21), which was not confirmed by Tukey's post-hoc multiple comparison tests applied subsequently (p>0.05). These

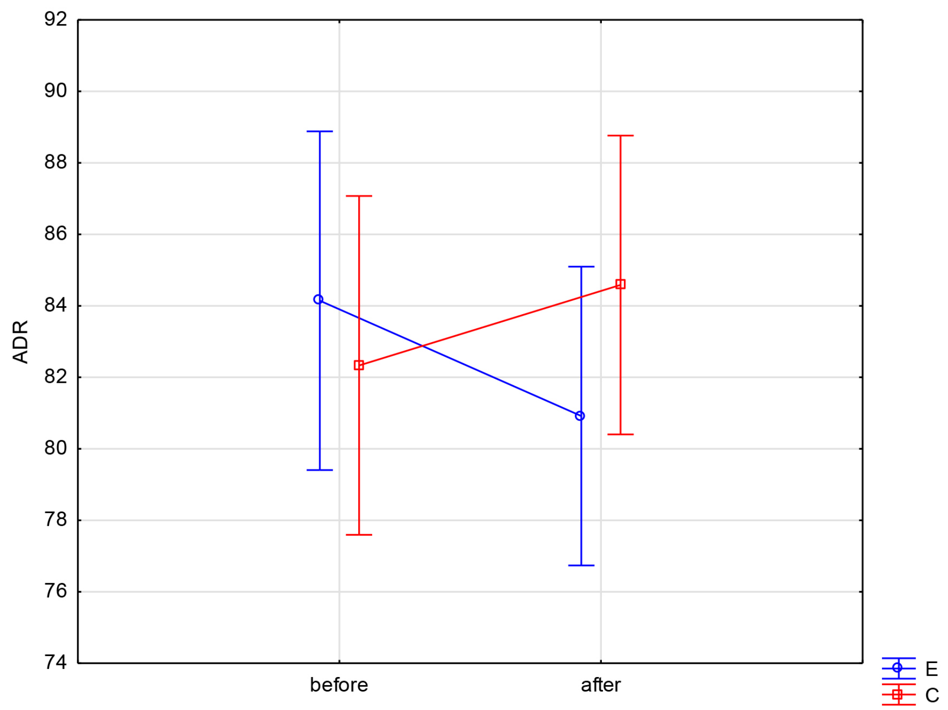

Figure 2. Comparison of mean values and confidence intervals for the ADR variable (anterior deltoid right activity presented as % of MVC) by group. *significant change in comparison to the pre-test $p<0.05$ for the same group, ** intragroup difference $p<0.05$ for repeated-measures ANOVA.

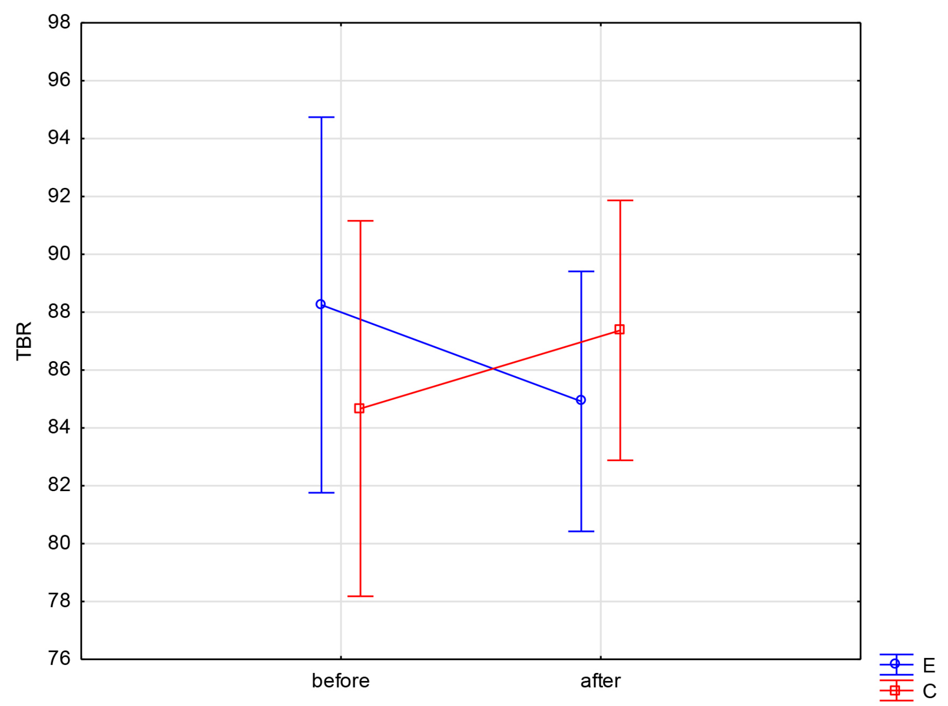

Figure 3. Comparison of mean values and confidence intervals for the TBR variable (triceps brachii right activity presented as % of MVC) by group. *significant change in comparison to the pre-test $p<0.05$ for the same group, ** intragroup difference $p<0.05$ for repeated-measures ANOVA.

results are supported by the figure shown below.

The analysis of the results for the dependent variable TMR led to the conclusion that no significant differences were found for the main effects of group (F=0.025; p=0.87) and pre-post (F=0.051; p=0.82). However, for the interaction group*pre-post, the analysis of variance allowed the rejection of the null hypothesis of no differences (F=4.66; p=0.04; η^2=0.17), which was not confirmed by Tukey's post-hoc multiple comparisons tests applied subsequently (p>0.05). These results are supported by the figure presented below.

Discussion

The process of changing movement patterns concentrates on the reduction of muscle asymmetries by activating less active muscle groups and partially deactivating those that are overactive. Movement pattern re-education also involves repeating activities while modifying the force of muscular contractions. To eliminate excess tension or change the range of motion in an exercise, potential sources of that movement must be eliminated. The study replaced the transitional position form with single joint exercises that target the activity of the pectoralis major muscle.

The analysis of EMG provides a reliable assessment of changes in the activity patterns of the muscles involved in resistance training[25]. The examination of the internal structure of movement makes it possible to identify deficits in muscular activity, thus preventing injuries and improving the effectiveness of training[37]. The results of the experiment indicate that a 10-week targeted training of the pectoralis major muscle increased its involvement during the BP exercise. The study found that the experimental group significantly increased the electromyographic activity of the pectoralis major after the intervention, while the control group showed no significant difference in PM activity during the flat bench press exercise. Previous studies have shown that muscles identified as least active following a period of targeted strength training increase their activity significantly as a result of such an intervention[31,38,39] also found evidence that a change in activity pattern is possible after a targeted resistance training intervention. The experiment demonstrated that muscle activity increases during the resistance training period, regardless of its initial activity. This increase in muscle activity may be attributed to changes in tonic muscle control resulting from the high frequency of muscle excitation[38].

After identifying muscular asymmetries, we can implement an intervention protocol to c the current movement pattern. There is a possibility of direct intervention, either through introducing additional exercises for the less active side or muscle group before the main training session, or through a 6–10-week targeted training intervention. This intervention can help reduce muscular asymmetries and modify movement patterns in the long term (delayed effects).

The findings of Stronska et al.[31] support those of this experiment, indicating that the pectoralis muscle requires a prolonged training period due to its large innervation area and low involvement in daily motor activities[41]. Specifically, the results demonstrate that targeted training of the pectoralis major for 10 weeks enhances its activity during conventional bench press.

Ethics approval

The study received the approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland (NRSA 404,054). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Consent to participate

All participants were informed about the experiment's procedure, potential benefits, and risks, as well as the option to withdraw from the study at any moment. Each participant provided written consent for the study.

Funding

This study was supported by Polish Ministry of physical Education [number NRSA3 03953 and NRSA4 040 54].

Authors' contributions

Concept and design: KS, AG, MD; Data collection: AG, KS, RR Data analysis: RR, AT; Writing: AT, KS, Editing assistance: MD, AG. All authors read and approved the final version of the manuscript.

References

1. Castillo F, Valverde T, Morales A, Pérez-Guerra A, de León F, García-Manso JM. Maximum power, optimal load and optimal power spectrum for power training in upper-body (bench press): a review. Revista Andaluza de Medicina Del Deporte 2012;5:18–27.
2. Gomo O, Van Den Tillaar R. The effects of grip width on sticking region in bench press. Journal of Sports Sciences 2015;34:232–8.
3. Stastny P, Gołaś A, Blazek D, Maszczyk A, Wilk M, Pietraszewski P, et al. A systematic review of surface electromyography analyses of the bench press movement task. PLOS ONE 2017;12:e0171632.
4. Gołaś A, Maszczyk A, Zajac A, Mikołajec K, Stastny P. Optimizing post activation potentiation for explosive activities in competitive sports. Journal of Human Kinetics 2016;52:95–106.
5. Trebs AA, Brandenburg JP, Pitney WA. An Electromyography Analysis of 3 Muscles Surrounding the Shoulder Joint During the Performance of a Chest Press Exercise at Several Angles. Journal of Strength and Conditioning Research 2010;24:1925–30.
6. Enoka RM, Duchateau J. Muscle fatigue: what, why and how it influences muscle function. The Journal of Physiology 2008;586:11–23.
7. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing Muscle Hypertrophy: A Systematic Review of Advanced Resistance Training Techniques and Methods. International Journal of Environmental Research and Public Health 2019;16:4897.

8. Westcott WL. Resistance Training is Medicine. Current Sports Medicine Reports 2012;11:209–16.
9. van den Tillaar R, Saeterbakken AH, Andersen V. The Acute Effects of Attaching Chains to the Barbell on Kinematics and Muscle Activation in Bench Press in Resistance-Trained Men. Journal of Functional Morphology and Kinesiology 2022;7:39.
10. Aboodarda SJ, Hamid MSA, Che Muhamed AM, Ibrahim F, Thompson M. Resultant muscle torque and electromyographic activity during high intensity elastic resistance and free weight exercises. European Journal of Sport Science 2011;13:155–63.
11. Israetel MA, McBride JM, Nuzzo JL, Skinner JW, Dayne AM. Kinetic and Kinematic Differences Between Squats Performed With and Without Elastic Bands. Journal of Strength and Conditioning Research 2010;24:190–4.
12. Dunnick DD, Brown LE, Coburn JW, Lynn SK, Barillas SR. Bench Press Upper-Body Muscle Activation Between Stable and Unstable Loads. Journal of Strength and Conditioning Research 2015;29:3279–83.
13. Lehman GJ. The Influence of Grip Width and Forearm Pronation/Supination on Upper-Body Myoelectric Activity During the Flat Bench Press. The Journal of Strength and Conditioning Research 2005;19:587.
14. Barnett C, Kippers V, Turner P. Effects of Variations of the Bench Press Exercise on the EMG Activity of Five Shoulder Muscles. The Journal of Strength and Conditioning Research 1995;9:222.
15. Mausehund L, Werkhausen A, Bartsch J, Krosshaug T. Understanding Bench Press Biomechanics—The Necessity of Measuring Lateral Barbell Forces. Journal of Strength and Conditioning Research 2021;36:2685–95.
16. Clemons JM, Aaron C. Effect of Grip Width on the Myoelectric Activity of the Prime Movers in the Bench Press. Journal of Strength and Conditioning Research 1997;11:82–7.
17. Welsch EA, Bird M, Mayhew JL. Electromyographic Activity of the Pectoralis Major and Anterior Deltoid Muscles During Three Upper-Body Lifts. The Journal of Strength and Conditioning Research 2005;19:449.
18. Muyor J, Rodríguez-Ridao D, Oliva-Lozano JM. Comparison of Muscle Activity between the Horizontal Bench Press and the Seated Chest Press Exercises Using Several Grips. Journal of Human Kinetics 2023;87:23–34.
19. Stronska K, Trebert M, Golas A, Maszczyk A, Pieta A, Tyrala F, et al. 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;10:7–14.
20. Fleck SJ, Kraemer WJ. Designing Resistance Training Programs-4th Edition. J Hum Kinet, Illinois: Champaign, 2014.
21. Egger G, Champion N, Hurst G. The Fitness Leaders Exercise Ninle (2nd ed.). Kenthrust, NSW: Kangaroo Press. 1989.
22. Glass SC, Armstrong T. Electromyographical activity of the pectoralis muscle during incline and decline bench presses. J Strength Cond Res. 1997; 11: 163-167.
23. Coratella G, Tornatore G, Longo S, Esposito F, Cè E. Specific prime movers' excitation during free-weight bench press variations and chest press machine in competitive bodybuilders. European Journal of Sport Science 2019;20:571–9.
24. Jagessar M, Gray M. Optimizing Development of the Pectoralis Major. Sport J. 2010.
25. Golas A, Maszczyk A, Pietraszewski P, Wilk M, Stastny P, Strońska K, Studencki M, Zając A. Muscular activity patterns of female and male athletes during the flat bench press. Biol Sport. 2018; 35(2), 175-179.
26. Lagally KM, McCaw ST, Young GT, Medema HC, Thomas DQ. Ratings of perceived exertion and muscle activity during the bench press exercise in recreational and novice lifters. J Strength Cond Res. 2004; 18(2): 359-364.
27. Saeterbakken AH, Stien N, Pedersen H, Solstad TEJ, Cumming KT, Andersen V. The Effect of Grip Width on Muscle Strength and Electromyographic Activity in Bench Press among Novice- and Resistance-Trained Men. International Journal of Environmental Research and Public Health 2021;18:6444.
28. Harøy J, Clarsen B, Wiger EG, Øyen MG, Serner A, Thorborg K, et al. The Adductor Strengthening Programme prevents groin problems among male football players: a cluster-randomised controlled trial. British Journal of Sports Medicine 2018;53:150–7.
29. Jensen J, Hölmich P, Bandholm T, Zebis MK, Andersen LL, Thorborg K. Eccentric strengthening effect of hip-adductor training with elastic bands in soccer players: a randomised controlled trial. British Journal of Sports Medicine 2012;48:332–8.
30. Mjølsnes R, Arnason A, Østhagen T, Raastad T, Bahr R. A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. Scandinavian Journal of Medicine & Science in Sports 2004;14:311–7.
31. Stronska K, Golas A, Wilk M, Zajac A, Maszczyk A, Stastny P. The effect of targeted resistance training on bench press performance and the alternation of prime mover muscle activation patterns. Sports Biomechanics 2020;21:1262–76.
32. Coratella G. Appropriate Reporting of Exercise Variables in Resistance Training Protocols: Much more than Load and Number of Repetitions. Sports Medicine - Open 2022;8.
33. Konrad P. Abc of Emg: A practical Introduction to Kinesiological Electromyography. Noraxon INC. USA. 2006.
34. Delavier F, Gundill M. Strength Training Anatomy Workout Three. Human Kinetics Publishers; 2019.
35. Hermens, HJ, Freriks B, Disselhorst-Klug C, Rau,G. Development of recommendations for SEMG sensors and sensor placement procedures. J. Electromyogr.

Kinesiol 2000;10:361–374.
36. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Routledge; 2013.
37. Serner A, Jakobsen MD, Andersen LL, Hölmich P, Sundstrup E, and Thorborg K. EMG evaluation of hip adduction exercises for soccer players: implications for exercise selection in prevention and treatment of groin injuries. Br J Sports Med. 2014;48:1108-1114.
38. van den Tillaar R, Saeterbakken AH, and Ettema G. Is the occurrence of the sticking region the result of diminishing potentiation in bench press? J Sports Sci 2012;30:591-599.
39. Maszczyk A, Czuba M, Krol H, Wilk M, Kostrzewa M, Zajac A, Stastny P, and Goodwin J. EMG analysis and modelling of Flat Bench Press using artificial neural networks. South African Journal for Research in Sport, Physical Education and Recreation 2016;38:91-103.
40. Duchateau J, Enoka RM. Human motor unit recordings: origins and insight into the integrated motor system. Brain Res 2011;1409: 42-61.
41. Drake R, Vogl A, and Mitchell A. Gray's Anatomy for Students. 3rd edn Philadelphia, PA: Churchill Livingstone. Elsevier. 2016.