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Neuromuscular Control during the Bench Press Exercise Performed with Free Weights and Pneumatic Loading

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Abstract: The main objective of the research was to determine neuromuscular control for different external loads, from 75% to 100% 1 RM (One Rep Max), during the flat bench press (BP) exercise performed with free weights and pneumatic loading. Despite extensive research on the internal structure of the BP exercise, few studies have examined the differences between muscular activity during the flat bench press movement between Free Weights and Pneumatic Loading. For this purpose, 10 male, trained subjects performed the BP exercise under two conditions with three different external loads (70%, 85%, and 100% 1RM), alternately with free weights and pneumatic loading. Pneumatic loading was performed on the Keiser Power Rack, where the pneumatic load was transferred as the resistance of the cables attached to the ground. EMG activity was recorded during the lifts for the following muscles: PM (Pectoralis Major), AD (Anterior Deltoid), Tblat, and TBlong (Triceps Brachii). The EMG signals were sampled at a rate of 1000 Hz. Signals were band-pass filtered with a cutoff frequency of 8 Hz and 450 Hz, after which the root-mean-square (RMS) was calculated. After completion of all the tests in a single day, 2–3 s evaluations of Maximal Voluntary Isometric Contraction (MVIC) of the prime movers in the bench press movement (AD, PM, and TBlong) were performed according to SENIAM procedures. The results of the present study indicate that pneumatic loading provides a significantly different muscle activation pattern compared to a standard bar during a heavy-loaded BP exercise. The pneumatic load was superior in activating the AD and TB muscles compared to the standard bar during the BP exercise.

Keywords: movement pattern; muscular activity; resistance training

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1. Introduction

One of the most often used resistance exercises for the upper body includes the bench press (BP). Considering its effectiveness in building strength and power, it is used by athletes in numerous sports disciplines [1]. A successful bench press lift is performed when the barbell is first lowered to the chest and then moved to a fully extended position. The bench press consists of two phases: the ascending and descending phases. Bench press performance is evaluated by the maximal weight that can be lowered to the chest and lifted (pushed up) to full extension of the elbow joints [2].

The functional effectiveness of motor actions can be evaluated on the basis of the obtained athletic results. In the context of bench pressing, objectives may include maximizing strength, promoting muscle hypertrophy, achieving symmetrical muscle development, or mastering a technique conducive to lifting the heaviest weight feasible. The bench press's capacity for strength enhancement and the prevalence of bench press competitions render it a distinctive phenomenon, widely adopted as an exercise for training, assessment, or scholarly inquiry. Previous research has investigated various aspects, such as the kinematics of the bench press movement [3], the effects of different chest press exercises [4], the utilization of unstable surfaces [5], the influence of fatigue [3], as well as analyses of both successful and unsuccessful attempts [2], and diverse approaches to the bench press.

Professional bench pressing is related to a very reproducible movement pattern that is adapted to individual anthropometric characteristics. Numerous approaches are used in perfecting the bench pressing technique which includes grip width, angle, and bench inclination angle variation. Implementation of dumbbells, unstable surfaces, and different types of bars are used to enhance balance and coordination. Numerous investigations examining the muscular strength topography delineate the specific muscle groups' contributions to overall strength. Thus far, neuromuscular recruitment has primarily been evaluated through EMG (electromyography) amplitude to gauge the impact of exercise load as an external stimulus for enhanced muscular development. EMG analysis yields five principal categories of data: muscle activity, level of muscle engagement, timing of muscle activation and deactivation, extent of muscle activation, and degree of fatigue. Initially, it is imperative to contemplate the tonic aspect of neurophysiological motor unit behavior during muscular contraction, which correlates with the intensity of muscular activation. The electromyography activity of the muscles involved in the movement of the bench press exercise has been extensively studied and detailed in the scientific literature [6–8]. Few attempts have been made to examine the differences in muscular activity during the flat bench press movement performed with Free Weights and Pneumatic Loading. Changes in the technique of resistance exercises can be evaluated by electromyography (EMG) amplitude, which is reflective of neuromuscular recruitment. The central nervous system (CNS) is responsible for processing information received from the environment and commanding a response from the rest of the body. Neural pathways that are well used and developed are retained and promoted, whereas those that are less needed in the present situation will be pruned or shut down to qualify the release of brain capacity.

Load is a measure of the intensity of a training session or how much stress that session places on the body. Three things define this for an athlete: External training load: "work" or "volume" (total distance run, amount of weight lifted, number of sprints, jumps to rebound a basketball, collisions in football, etc.).

Until now, only the tonic aspect of the neurophysiological behavior of motor units during muscular contractions related to the intensity of exercise has been considered [9]. The neuromuscular control signal information is encoded in geometric, time, and frequency domains. The root mean square (RMS) value determines the geometry and time characteristics of motor units during a contraction. This is quite significant for the tonic and phase characteristics of neuromuscular control, especially as it pertains to resistance training exercises. As stated, most EMG data related to the bench press has been collected during this exercise performed with the standard bar [8]. There is no data about the muscular activity during the bench press exercise performed with pneumatic loading. Thus, the main objective of the study was to determine the differences in neuromuscular control for various external loads, from 70 to 100% 1RM (One Rep Max), during the flat bench press performed with free weights and pneumatic loading.

2. Materials and Methods

2.1. Participants

Ten strength-trained male athletes (age 24 ± 2.5 yrs, body mass 95.4 ± 12.5 kg, body height 179 ± 8.7 cm) participated in the study. All participants had good technique in the bench press, were experienced with the performance of this exercise, and their personal record was at least 70 kg. The participants did not perform any additional resistance exercises for 72 h 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 the approval of the Bioethics Committee at the Academy of Physical Education in Katowice, Poland.

2.2. Procedures

The measurements were performed in the Strength and Power Laboratory at the Academy of Physical Education in Katowice. Four weeks before the experiment, the participants were familiarized with the study design in order to improve the technique of the pneumatic bar bench press. Afterwards, the participants attended two testing sessions. Session 1 was used to determine the value of the one-repetition maximum (1RM) of the flat bench press. Session 2 consisted of performing the flat bench press exercise with increasing loads (75%, 85%, and 100% 1RM), alternately with the free weights and a pneumatic loading. Pneumatic loading was performed on the Keiser Power Rack, where the pneumatic load was transferred as the resistance of the cables attached to the ground. The pneumatic loading apparatus allows for a natural barbell movement. A general warm-up protocol was used which included 5 min of hand cycling (cardio warm-up) and several 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.

The determination of 1RM was performed according to the protocol by Tillaar and Saeterbakken (2014). The 1RM load was determined based on the self-reported values of the athletes. The reported 1RM data on maximal lifts was acquired over the previous three months. The rest intervals between sets equaled 5 min to secure full recovery and avoid the potential effects of fatigue. When the self-reported 1RM was successful, a trial with an additional load of 2.5–5 kg was performed. When the initial trial was unsuccessful, the weight was decreased by 2.5–5 kg. A total of two to three trials were performed per athlete. The tempo of movement of all bench press exercises was controlled by a metronome (Korg MA-30, Korg, Melville, NY, USA). In the second testing session, the flat bench press exercise was performed with progressive loads (30%, 50%, 70%, 90%, and 100% 1RM), alternately with free weights and pneumatic equipment.

2.3. Electromyography

An eight-channel Noraxon TeleMyo 2400 system (Noraxon USA Inc., Scottsdale, AZ, USA; 1500 Hz) was used for recording and analysis of biopotentials from the muscles. The activity was recorded for three muscles: PM (Pectoralis Major), AD (Anterior Deltoid), TBlat, and TBlong (Triceps Brachii). Before placing the gel-coated self-adhesive electrodes (Dri-Stick Silver circular sEMG Electrodes AE-131, NeuroDyne Medical, Germantown, TN, 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 [10]. The EMG signals were sampled at a rate of 1000 Hz. Signals were band-pass filtered with a cutoff frequency of 8 Hz and 450 Hz, after which the root-mean-square (RMS) was calculated. 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. After completion of all the tests in a single day, 2–3 s evaluations of Maximal Voluntary Isometric Contraction (MVIC) of the prime movers in the bench press movement (AD, PM, and TBlong) were performed according to the SENIAM procedure. These evaluations were performed in order to normalize electromyographic records. The analysis was based on peak activity during the bench press exercise from both, the eccentric and concentric phases of the movement. Due to the large amount of data covering three different loads and the right and left sides of the body separately, the analysis was limited only to the analysis of the peak activity of the tested muscles in order to determine the differences between muscle involvement under free load and under pneumatic load.

2.4. Statistical Analysis

All statistical analyses were performed using Statistica 13.1. The results were presented as means with standard deviations, standard errors, and 95% confidence intervals. The Shapiro-Wilk, Leaven's, and Mauchly's tests were used in order to verify the normality, homogeneity, and sphericity of the sample data variances, respectively. A two-way repeated measures ANOVA was used to compare the differences between the considered variables. Effect sizes for main effects and interactions were determined by partial eta squared (η^2). The ES were classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (>0.137). In case of significant differences for main effect or interaction, post hoc comparisons were conducted using Tukey's post hoc test. The statistical significance for the differences between the type of loads and muscle side was set at $p < 0.05$. Effect Sizes (Cohen's d) were also calculated. The ES was interpreted as large for d > 0.8, moderate for d between 0.8 and 0.5, and small for d < 0.5.

3. Results

3.1. ANterior Deltoid Muscle Activity

A two-way repeated measures analysis of variance (Table 1) indicated significant differences in the muscular activity of the AD between free weights and the pneumatic loading in the case of 70% 1RM (F = 10.46; $p = 0.0026$; ES = 0.23) and 85% 1RM (F = 4.82; $p = 0.03$; ES = 0.12). No significant difference was observed in the case of 100% 1RM (F = 2.05; $p = 0.16$; ES = 0.05). To verify between which interactions significant differences occurred, multiple comparisons post-hoc Tuckey's tests were applied. For the 70% 1RM significant differences were registered between the activity of the anterior deltoid for the left (AD-LS) and right side (AD-RS) for the free weights ($p = 0.0002$). In the case of free weights, the activity for the AD-RS (m = 92.90) was significantly higher in comparison to the AD-LS (m = 79.4); d = 2.06. Significant differences were also detected between the activity of AD-RS (m = 77.1% MVIC; $p = 0.002$; d = 2.94) and AD-LS (m = 74.7; $p = 0.02$; d = 3.20) for the pneumatic load indicating significantly lower activity of the AD-RS (m = 92.2) in the free weights. For the free weights, the activity of AD-RS (97.4% MVIC (Maximum Voluntary Isometric Contraction) was significantly higher than AD-LS (88.1% MVIC). Significant differences were also determined for the load of 85% 1RM between the pneumatic loading of AD-LS (m = 81.8% MVIC; $p = 0.002$; d = 2.70) and AD-RS (m = 84.2% MVIC; $p = 0.002$; d = 2.78) for which the activity was significantly lower than that recorded for the free weights AD-RS (m = 97.4% MVIC). Also, significantly greater activity ($p = 0.036$; d = 1.21) for the AD-LS (m = 88.1% MVIC) was observed for the free weights compared to AD-LS during pneumatic loading (m = 81.80% MVIC).

Table 1. Descriptive statistics for the left and right side of the Anterior Deltoid and type of load (free and pneumatic loading) $n = 10$.

% 1RM	Type of Load	Anterior Deltoid	Mean [%MVIC]	SD	SE	CI −95%	CI +95%	ANOVA F/p/ES
70%	Pneumatic	Left Side (AD-LS)	74.70 #	4.42	1.40	71.54	77.86	F = 10.46 p = 0.0026 ES = 0.23
	Pneumatic	Right Side (AD-PS)	77.10 ^	3.57	1.13	74.54	79.66	
	Barbells	Left Side (AD-LS)	79.40 **	6.35	2.01	74.86	83.94	
	Barbells	Right Side (AD-PS)	92.90 **′#′^	6.72	2.13	88.09	97.71	
85%	Pneumatic	Left Side (AD-LS)	81.80 #′$	5.79	1.83	77.66	85.94	F = 4.82 p = 0.03 ES = 0.12
	Pneumatic	Right Side (AD-PS)	84.20 #	3.43	1.08	81.75	86.65	
	Barbells	Left Side (AD-LS)	88.10 *′$	4.51	1.43	84.88	91.32	
	Barbells	Right Side (AD-PS)	97.40 *′#′^	5.76	1.82	93.28	101.52	

Table 1. *Cont.*

% 1RM	Type of Load	Anterior Deltoid	Mean [%MVIC]	SD	SE	CI −95%	CI +95%	ANOVA F/*p*/ES
100%	Pneumatic	Left Side (AD-LS)	93.20	6.63	2.10	88.46	97.94	F = 2.05 *p* = 0.16 ES = 0.05
	Pneumatic	Right Side (AD-PS)	95.00	4.62	1.46	91.70	98.30	
	Barbells	Left Side (AD-LS)	95.20	6.84	2.16	90.30	100.10	
	Barbells	Right Side (AD-PS)	102.50	5.97	1.89	98.23	106.77	

** $p \leq 0.001$; * $p \leq 0.01$; $^{\hat{},\#}$ $p \leq 0.001$; $^{\$}$ $p \leq 0.05$.

3.2. Pectoralis Major Muscle Activity

The results of the two-way repeated analysis of variance for the pectoralis major muscle (Table 2) showed no significant differences in muscle activity between pneumatic loading and free weights for neither of the three applied loads: 70% 1RM (F = 2.21; $p = 0.15$; ES = 0.06); 85% 1RM (F = 0.38; $p = 0.84$; ES = 0.001) and 100% 1RM (F = 2.05; $p = 0.16$; ES = 0.05).

Table 2. Descriptive statistics for the left and right side of the Pectoralis Major and the type of load (free and pneumatic loading) N = 10.

% 1RM	Type of Load	Pectoralis Major Muscle	Mean [%MVIC]	SD	SE	CI −95%	CI +95%	ANOVA F/*p*/ES
70%	Pneumatic	Left Side (AD-LS)	49.30	3.43	1.09	46.84	51.76	F = 2.21 *p* = 0.15 ES = 0.06
	Pneumatic	Right Side (AD-PS)	58.20	4.32	1.36	55.11	61.29	
	Barbells	Left Side (AD-LS)	35.70	4.40	1.39	32.55	38.85	
	Barbells	Right Side (AD-PS)	40.70	4.37	1.38	37.57	43.83	
85%	Pneumatic	Left Side (AD-LS)	64.00	4.24	1.34	60.96	67.04	F = 0.38 *p* = 0.84 ES = 0.001
	Pneumatic	Right Side (AD-PS)	75.50	4.17	1.32	72.52	78.48	
	Barbells	Left Side (AD-LS)	41.60	3.34	1.06	39.21	43.99	
	Barbells	Right Side (AD-PS)	53.60	4.48	1.42	50.40	56.80	
100%	Pneumatic	Left Side (AD-LS)	75.20	5.96	1.88	70.94	79.46	F = 2.05 *p* = 0.16 ES = 0.05
	Pneumatic	Right Side (AD-PS)	87.50	4.48	1.42	84.30	90.70	
	Barbells	Left Side (AD-LS)	61.00	4.22	1.33	57.98	64.02	
	Barbells	Right Side (AD-PS)	70.00	4.81	1.52	66.56	73.44	

3.3. Triceps Brachii Muscle Activity

The results of the two-way analysis of variance for the triceps brachii muscle (Table 3) showed no significant differences in muscle activity between pneumatic loading and free weights for 70% 1RM (F = 0.64; $p = 0.43$; ES = 0.02) and 100% 1RM (F = 0.81; $p = 0.37$; ES = 0.02). Statistically significant differences between pneumatic loading and free weights were observed only for 85% 1RM (F = 10.15; $p = 0.003$; ES = 0.22). For the 85% 1RM loading significant differences occurred (Table 3) between TB-LS (left side) and TB-RS (right side) for the pneumatic loading ($p = 0.019$; d = 1.47) in which the activity of TB-RS was (m = 89.9% MVIC), which was significantly higher than TB-LS (m = 83.9% MVIC). Significant differences were also determined between the activity of TB-RS during pneumatic loading (m = 89.9% MVIC; $p = 0.0002$) which was significantly higher than the activity of the TB-LS (m = 79.1% MVIC; d = 2.96) and TB-RS (m = 76.4% MVIC; d = 2.76) registered with the free weights. The activity of the TB-LS with the pneumatic loading (m = 83.9% MVIC) was significantly higher compared with the activity of TB-RS performed with free weights (m = 76.4% MVIC; d = 1.53).

Table 3. Descriptive statistics for e side of Triceps Brachii and type of load (free and pneumatic loading) N = 10.

% 1RM	Type of Load	Triceps Brachii Muscle	Mean [%MVIC]	SD	SE	CI −95%	CI +95%	ANOVA F/*p*/ES
70%	Pneumatic	Left Side (AD-LS)	73.20	4.87	1.54	69.72	76.68	F = 0.64 *p* = 0.43 ES = 0.02
	Pneumatic	Right Side (AD-PS)	79.20	4.87	1.54	75.72	82.68	
	Barbells	Left Side (AD-LS)	69.20	5.63	1.78	65.17	73.23	
	Barbells	Right Side (AD-PS)	72.60	5.08	1.61	68.96	76.24	
85%	Pneumatic	Left Side (AD-LS)	83.90 $^{*\prime\wedge}$	4.09	1.29	80.97	86.83	F = 10.15 *p* = 0.003 ES = 0.22
	Pneumatic	Right Side (AD-PS)	89.90 $^{*\prime\#\prime\$}$	4.09	1.29	86.97	92.83	
	Barbells	Left Side (AD-LS)	79.10 $^{\#}$	3.14	0.99	76.85	81.35	
	Barbells	Right Side (AD-PS)	76.40 $^{\wedge\prime\$}$	5.58	1.77	72.41	80.39	
100%	Pneumatic	Left Side (AD-LS)	102.50	5.38	1.70	98.65	106.35	F = 0.81 *p* = 0.37 ES = 0.02
	Pneumatic	Right Side (AD-PS)	105.70	4.99	1.58	102.13	109.27	
	Barbells	Left Side (AD-LS)	91.50	2.72	0.86	89.56	93.44	
	Barbells	Right Side (AD-PS)	97.50	5.99	1.89	93.22	101.78	

* $p \leq 0.05$; $^{\wedge}$ $p \leq 0.01$; $^{\#}$ $p \leq 0.001$; $^{\$}$ $p \leq 0.001$.

4. Discussion

The bench press (BP) is one of the most popular upper-body resistance exercises, with numerous variations (e.g., flat, incline, decline) commonly used in practice [11]. The BP is an integral part of resistance training programs used by most athletes to increase strength and gain upper-body muscle mass. The bench press is a compound exercise that involves the pectoralis major of the chest, the anterior deltoids of the shoulder, and the triceps brachii of the upper arm. The bench press exercise has a pushing movement pattern and can change muscle balance for athletes who mainly perform pulling actions in their sports disciplines. The bench press is also a major competitive lift in powerlifting.

The aim of this study was to compare the peak muscle activity of the prime movers during the standard barbell bench press with a pneumatic-loaded device for different external loads (70%, 85%, and 100% 1RM). Previous studies have examined the: kinematics of the bench press movement, the effect of different chest press exercises, unstable surfaces, the impact of fatigue as well as successful and unsuccessful attempts, and different approaches in the bench press exercise [12,13]. However, there is little data related to the comparison of the standard bar bench press and its equivalent performed with a pneumatic load. The main finding of the present investigation indicates significant differences in muscular activity of the AD between free weights and pneumatic loading in the case of 70% 1RM and 85% 1RM and the case of the TB between free weights and pneumatic loading in the case of 85% 1RM. This is the first study that compares the impact of pneumatic loading on bench press performance, as well as the neuromuscular activity of the prime movers on both sides of the body. It must be indicated that most authors studying the bench press exercise [3] evaluated EMG only from the dominant side of the body. Our research has shown that muscle activity of the dominant and non-dominant side of the body can differ significantly. The difference in EMG activities of particular muscles on both sides of the body may reflect acquired movement patterns through long-term training, different levels of muscular strength of these muscles, and past injuries [14].

For 0% and 85%1RM significant differences were registered between the activity of the AD muscle for the left and right side for free weights. Greater muscular activity results from systematic training which is most often attributed to a combination of greater recruitment (the number of fibers involved in a muscle action), and higher rate coding (the frequency at which the motor units are stimulated) [15,16]. Significant differences were also determined for 85% 1RM between pneumatic loading, for which the activity was significantly lower than that recorded for free weights. Also, significantly greater activity for the AD-LS was observed for free weights compared to the same muscle group during pneumatic loading.

Statistically significant differences in muscular activity of the TB between pneumatic loading and free weights were observed only for 85% 1RM. For 85% 1RM loading significant differences occurred between TB-LS and TB-RS between pneumatic loading and free weights in which the activity of TB-RS was significantly higher than TB-LS. The activity of the TB with the pneumatic loading was significantly higher, compared to the activity of TB performed with free weights. The TB is mainly composed of type II muscle fibers, which are utilized to a greater extent during tasks of higher force production, which may explain the significantly greater peak amplitude of the TB with pneumatic loading compared to a standard bar. The results for the pectoralis major showed no significant differences in muscle activity between pneumatic loading and free weights, for neither of the three applied loads.

Our results indicate that during the two different exercise conditions (free weights and pneumatic loading) there is a different activation pattern, which means that particular prime movers are recruited in a different sequence and activated to a greater or lower extent.

The observed variations in EMG activity between the two distinct conditions of executing the flat bench press likely stem from tonic muscle control mechanisms. When performing a motor task, the central nervous system (CNS) orchestrates the activation of specific muscle groups in a predetermined sequence. However, the activation of primary movers during a particular exercise may not remain constant when external loads change [17]. Brennecke [18] proposes alternative principles of muscular activation, with the first principle emphasizing minimal energy expenditure. The second principle is founded on the anticipation of external forces, such as gravity, while the third principle involves muscle synergy across specific body segments. The recruitment of motor units and their firing frequency are governed by the central command of the CNS and may be modulated by reciprocal feedback mechanisms [19]. Resistance training under varied conditions engenders novel muscular patterns, facilitating additional adaptive changes within both the muscles and the CNS.

Certain study limitations should be acknowledged. One methodological limitation of this study is that evaluation of the external structure of the movement (i.e., forces and movement torques) was not investigated, nor was the kinematics of the two bench press lifts. Future research should consider the biomechanics of free weights and pneumatic loading in different populations of athletes, both female and male [17] as has already been carried out in other sporting disciplines [20,21]. The sample size is small, the EMG amplitude was analyzed only on the basis of peak values. Furthermore, the sEMG amplitude of the antagonist and stabilizer muscles was not considered. Moreover, the differences in the thickness of the subcutaneous tissue and the presence of the innervation zone, which could have influenced the obtained results, were not controlled. These studies should also determine the differences in technical characteristics of the standard pneumatic bench press exercise.

Changing the activity pattern in the same exercise but in different conditions of muscle strength allows for reduced tension in overactive muscle groups and greater involvement in less engaged groups.

It might seem that using a traditional load and pneumatic loading is identical, yet the forces acting on the body during movement, such as acceleration, friction, and inertia, can cause changes in the perceived load during movement. In the case of traditional loading, imparting momentum in the first stage of motion causes the weight to become smaller in the next stage. In the case of pneumatic machines, the resistance and weight throughout the movement remain the same, no matter how fast we perform the exercise. The benefit of decreased inertia not only reduces injury and strain but also makes each movement more efficient as the user is never able to gain momentum and lift their own weight.

5. Conclusions

The results of the present study indicate that pneumatic loading provides a significantly different muscle activation pattern compared to a standard bar during a heavy-loaded BP exercise. The pneumatic load was superior in activating the AD and TB muscles compared to the standard bar during the BP exercise. In practice, this can be of great significance while developing strength and power in the initial phase of this process. Proper and proportional involvement of all muscle groups during the training process will positively affect the harmonious development of the trained skills and will reduce the risk of muscular asymmetries. This approach can be of great importance in the prevention of injuries caused by inappropriate muscle activation during resistance exercise.

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