LOCOMOTOR APPARATUS IN EXERCISE AND SPORTS

ORIGINAL ARTICLE

ELECTROMYOGRAPHIC STUDY OF THE DELTOID, PECTORALIS MAJOR AND TRICEPS BRACHII MUSCLES IN SWIMMERS DURING BILATERAL CONTRACTIONS PERFORMED IN MULTI-JOINT EXERCISE WITH DIFFERENT LOADS

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ABSTRACT

The objective of this study was to compare the electrical activity of the deltoid (middle portion), pectoralis major (clavicular portion) and triceps (long head) muscles during bilateral contraction performed in a multi-articulated joint shoulder-press convergent machine with 40% and 80% maximum voluntary load (MVL) in 11 male swimmers (15 to 23 years, 70 ± 4 kg, 183 ± 6 cm and 10 ± 4 years' time of practice in sport), trained in resistance exercise. Electromyographic signals (EMG) were obtained by placing surface active differential electrodes (20 x gain), composed of two parallel rectangular bars (EMG System, Brazil®). A data acquisition system (EMG-Alc) which provided numerical data in RMS (Root Mean Square) to analyze the signals composed by a reference electrode (ground) and a signal conditioning module (EMG) with simultaneous acquisition of up to 8 differential channels (band-pass filter 5-20 Hz), adjustable amplifier stage, allowing gains between 100 and 4960 times, channel input impedance 10GΩ in differential modules and CMRR of 93 dB/60 Hz was used. Only the concentric phase (3 seconds duration) in each EMG signal collected was recorded. After the tests (Mann-Whitney U test, Friedman and Wilcoxon) were applied, it was concluded that for prescription and periodization of the neuromuscular training, bilateral contractions performed in the shoulder-press apparatus are efficient at aiming muscular recruitment (80%> 40%) of middle portion of the deltoid, pectoralis major (clavicular portion), and triceps brachii (long head) muscles, evidencing differences between dominant and non-dominant limbs only for the dominant brachial triceps in 80% of MVL in swimmers trained in resistance exercises.

Keywords: EMG, development, resistance exercise, swimmers.

INTRODUCTION

In the past, resistance training programs were based on the experiences of the coach or athlete, and science as support in the resistance training programs was avoided, which made both beginner and experienced athletes confused[1]. In fact, science was slow in validating the adopted practices in the resistance training.

Over the last years,many researchers have dedicated their time to the scientific study of the effects of different types of strength training in humans, with the aim to validate the basic exercises for physical fitness programs of athletes and non-athletes [2-6]. In those investigations, a series of comparisons between the deltoid, pectoralis major and triceps brachii muscles as well as comparisons between the different portions of a single muscle have been performed[2,7].

In the sports field, some electromyographic work has approached the participation of the pectoralis major, latissimusdorsi, deltoid among other muscles, in a rowing simulator[8] and in swimmers from different categories, simulating backstroke and crawl unilateral exercises[9,10]. However, with the increasing use of resistance exercises by swimming athletes with higher strength levels and performance improvement as goal, new investigations on this modality of exercises and action of different muscles during their performance become necessary.

Thus, the aim of this study was to compare the electromyographic signs emitted by the deltoid medialis, pectoralis major (clavicular portion) and triceps brachii muscles (long head) of the dominant and non-dominant limbs of 11 swimmers during bilateral contractions in the multi-articulated joint shoulder-pressconvergent machine.

METHODOLOGY

Sample

Participated in this study 11 male swimmers, practitioners of resistance exercise, aged between 19 ± 4 years, body mass 70 ± 4kg, height 183 ± 6cm and time of practice in the sport of 10 ± 4 years, participated in the study, and the resistance exercises were part of their training. The volunteers did not present history of osteomyo articular diseases which could interfere in the results.

Maximum Voluntary Load Test

All volunteers were submitted one day before the collection to a test of concentric bilateral maximum voluntary load (MVL) performed according to Nazário-de-Rezende*et al.*[11]. The load adopted for the study was of 40% and 80% of MLV, an intensity to which all volunteers were submitted during the annual training sessions.

General Procedures

Before performance of the electromyographic signs, the volunteers received information about the research and were submitted to familiarization procedures. The volunteers underwent explanations and simulations on the most suitable posture for the performance of exercise, initial and final position of each movement, performance velocity and the verbal command given by the electromyography technician. Subsequently, they signed a consent form for participation in the study and release of the results according to resolution # 196/96 of the National Board of Health.

In order to establish specific muscular preparation, the volunteers performed three sets with 15 repetitions without load..

Electrode

Skin sanitation and shaving was performed for acquisition of the electric activity (EMG) of the muscles. The electrodes used were simple differential active surface ones (Lynx Eletronics Ltda., São Paulo, SP, Brazil), composed of two parallel rectangular bars of pure silver (Ag), each one 10mm-long, 1mm-wide and 10mm distant from each other;20mm-wide by 41mm-long and 5mm-thick acrylic resin capsule; 1m-long cable; gain of 20 times; CMRR (*common mode rejection rate*) of 84 dBn and Earth plate electrode (Bio-logic Systems Corp. – SP Médica, Científica e Comercial Ltda., São Paulo, SP, Brazil), composed of a stainless steel disc measuring 30mm in diameter and 1.5mm-thick an 1m cable attached, which was placed on the head of the ulna of the volunteers, with the aim to eliminate external interferences[12].

The electrodes were attached to the skin; on the deltoid medialis muscles positioned approximately 4 ± 2cm away from the lateral border of the acromion, in a region where the higher volume of the muscle surface was clear. Concerning the triceps brachii (long head), the electrodes were attached according to Sousa *et al.*[2], 10 ± 1cm above the olecranon. Regarding the pectoralis major (clavicular portion) an activation maneuver was performed and the electrode was placed on the point of greatest muscular surface.

Electromyograph

EMG collection of the studied muscles was obtained through a sign conditioner module (electromyograph), with simultaneous acquisition of up to eight differential channels, entrance channel impedance of 10GΩ in differential modules, 12 *bits* of resolution band-pass filter of 20Hz to 5Hz and RRMC of 93db to 60Hz, entrance range of –10 to +10v and a data acquisition system (AIc-EMG) which provided numerical data in RMS (root mean square) for analysis of the results. The electromyograph was adjusted with gain of 4,960 times, guaranteeing hence the necessary amplification to the analog-digital conversion process and sample number of 6,000 and channel frequency of 2,000Hz, resulting in total acquisition time of three seconds.

Multi-articulated joint shoulder-pressconvergent machine

A machine named multi-articulated joint shoulder-press convergent, brand name MASTER was used for determination of the load in one repetition maximum (1RM) and performance of the bilateral exercise in the study. Such machine simulates the movement performed with dumbbells.

Movement performance

The volunteers sat on the machine with their trunk and head resting on the back and feet on the ground. After load selection with the volunteer already positioned, the electrodes were attached on the studied muscles. The movement started with arms in semi-abduction, forearms in flexion on frontal plane, prone hands front (figure 1).

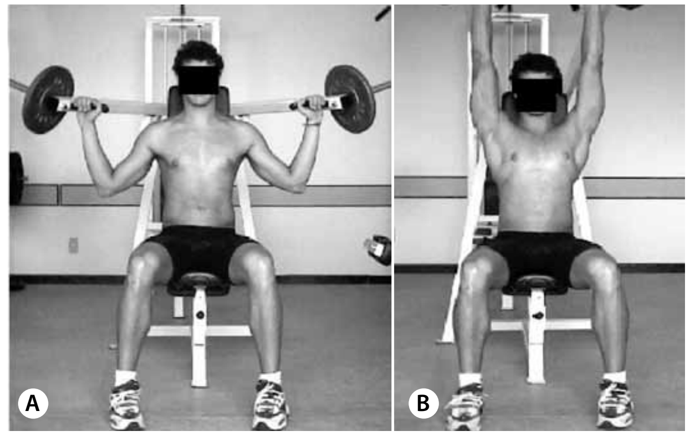

Figure 1. Multi-articulated joint shoulder-press convergent exercise: beginning of the bilateral movement (A) and end of the bilateral movement (B).

The movement occurred with arm abduction and forearm extension simultaneously following the path permitted by the machine, being this the concentric phase of the exercise which had duration of three seconds.

The electric signs in the bilateral tests were firstly picked with 40% and immediately after at 80% of MVL only in the concentric phase. Five trials were performed for better reproducibility and maximization of collection accuracy and statistical analysis.

Recovery interval

The volunteers were told not to perform any type of training on the day before the EMG recordings to avoid possible fatigue effects and alterations in the results[11].

The volunteers, after the end of the movement, remained seated, upper limbs facing down and parallel to the trunk and relaxed during five minutes of rest between trials, both for EMG recordings and for the MVL tests in order to avoid or minimize the fatigue effects[13]and replace their energetic supplies[14].

Goniometer

A plastic 35-cm long universal goniometer brand name CARCI, was used for measurement of the angles of the knee and elbow joints[15], prior to the tests performance, when the volunteer was already positioned at the machine.

Regarding the knee joint, the goniometer screw was placed on the lateral condyle of the femur, laterally aligned on the thigh longitudinal axis, from the trochanter major to the lateral condyle and on the axis between the fibula head until the lateral malleolus. On the elbow joint, the goniometer was aligned along the lateral medial line of the humerus, from the humerus head to the lateral epicondyle and the medial line of the radius until the radial styloid process.

The joint angles of the upper and lower limbs, at the beginning of the movement, have not been exactly delimited; however, the positionsof the knee joint (106º ± 5º) and elbow joint (105º ± 5º) were similar to those adopted in their training routines.

STATISTICAL ANALYSIS

The Wilcoxon and Student's *t* tests were applied to the data under consideration with the goal to verify the existence or absence of significant differences between the measures of the three muscles with 40% and 80% load for the 11 swimmers, with significance level adopted of 0.05 or 5% in a bilateral event.

RESULTS

The mean of the electric activity of the studied muscles is represented in tables 1, 2, 3 and 4. Note that when the 40% of 1RM load is analyzed (table 1 and figure 2), the mean values of the EMG signal of the sum of the dominant and non-dominant limbs for the deltoid, pectoralis and triceps muscles were 63.3%, 24% and 12.6%, respectively. Values significantly different are found when the EMG sum of the right and left deltoid is analyzed and compared with the sum of the EMG activity of the pectoralis activity. Significant differences were found in the 40% of 1RM load between the sum of the deltoid compared with the sum of the pectoralis sum ($p = 0.004$), between the deltoid sum with the triceps sum (p = 0,003) and the pectoralis sum with the triceps sum ($p = 0.009$). When the dominant and non-dominant limbs are compared, no significant difference was found (tables 2, 3 and figure 3, 4).

When the 80% of 1RM load (table 4 and figure 5) is analyzed, the mean values of the EMG sign of the sum of the dominant and non-dominant limbs for the deltoid, pectoralis and triceps muscles is50.5%, 35.9% and 13.5%, respectively, which are significantly different values. In the 80% loads we found significant differences between the EMG sum of the deltoid muscles compared with the pectoralis sum ($p = 0.036$), between the deltoid sum with the triceps sum ($p = 0.000$) and the pectoralis sum with the triceps sum ($p < 0.001$). As demonstrated in figure and table 2, when the dominant and non-dominant limbs were compared, no significant differences were found, except for the triceps, whose dominant side presented higher EMG sign ($p = 0.016$).

When the bilateral intermuscular kinesiologic activity is compared, the results presented in figures 3 and 4 were statistically the same with both loads (40% and 80%), and the deltoid muscle presented higher activity followed by the pectoralis and triceps ($p = 0.003$).

Table1. Values expressed in RMS (μv) of the electrical activity of the dominant deltoid (DD), non-dominant deltoid (NDD), dominant pectoralis(DP), non-dominant pectoralis (NDP), dominant triceps (DT) and non-dominant triceps (NDT) muscles of the 11 swimmers with 40% of MVL.

	Muscular contraction (expressed in μν)					
Volunteer	DD	NDD	DP	NDP	DT	NDT
1	620	893	115	170	136	111
2	776	409	306	581	238	256
3	616	667	302	216	212	160
4	710	420	295	295	350	169
5	604	1.137	105	151	106	166
6	1.241	439	200	195	111	102
7	415	556	447	644	53	58
8	407	583	321	173	171	116
9	376	785	285	372	86	95
10	2.134	965	261	269	204	127
11	531	962	225	251	113	93
Mean	766 ± 513	711 ± 253	260 ± 97	302 ± 167	162 ± 85	132 ± 54

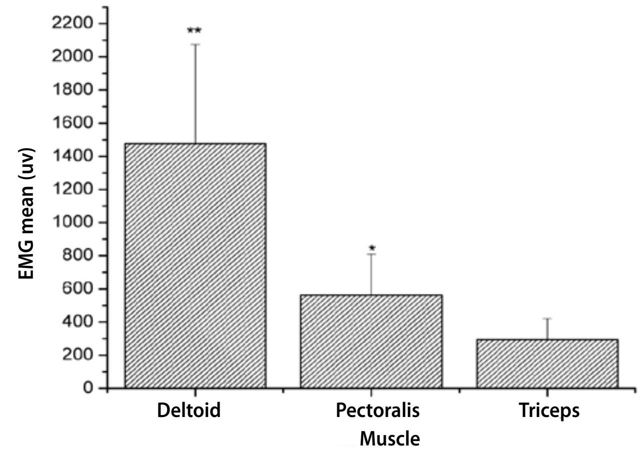

Figure 2. Values expressed in RMS (μv) of the summed mean electrical activity of the dominant deltoid with non-dominant deltoid, dominant pectoralis with non-dominant pectoralis and dominant triceps with non-dominant triceps muscles of the 11 swimmers with 40% of MVL.
*significance of 0.05.

Table 2. Values expressed in RMS (μν) of the electrical activity of the dominant deltoid (DD), non-dominant deltoid (NDD), dominant pectoralis(DP), non-dominant pectoralis(NDP), dominant triceps (DT) and non-dominant triceps muscles (NDT) of the 11 swimmers with 80% of MVL.

	Muscualr contraction (expressed in μν)					
Volunteer	DD	NDD	DP	NDP	DT	NDT
1	988	653	826	746	276	223
2	1.153	551	639	949	429	323
3	784	1.070	713	674	404	261
4	851	673	784	907	312	282
5	987	1.417	396	415	210	240
6	1.239	751	554	434	176	215
7	756	532	795	1.070	99	91
8	756	774	573	774	340	275
9	578	1.245	588	789	273	171
10	2.068	1.124	661	630	324	205
11	1.146	913	569	450	268	242
Mean	1.028 ± 400	882 ± 295	645 ± 128	713 ± 218	283* ± 96	230 ± 62

*significance of 0.05.

Table 3. Values expressed in RMS (μν) of the summed mean electrical activity of the dominant deltoid with the non-dominant deltoid, dominant pectoralis with non-dominant pectoralis, dominant triceps (DT) and non-dominant triceps muscles of the 11 swimmers with 40% of MVL.

	Muscles		
Volunteer	Deltoid	Pectoralis	Triceps
1	1.513	285	247
2	1.185	887	494
3	1.283	518	372
4	1.130	590	519
5	1.741	256	272
6	1.680	395	213
7	971	1.091	111
8	990	494	287
9	1.161	657	181
10	3.099	530	331
11	1.493	476	206
Mean/standard deviation	1.477** ± 598.3	562* ± 246.7	294 ± 127

*significance of 0.05.

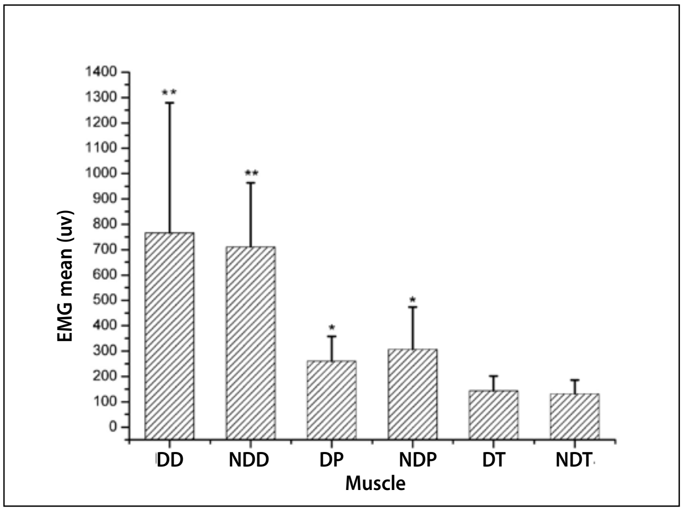

Figure 3. Values expressed in RMS (μv) of the electrical activity of the dominant deltoid (DD), non-dominant deltoid (NDD), dominant pectoralis(DP), non-dominant pectoralis(NDP), dominant triceps (DT) and non-dominant triceps (NDT) muscles of the 11 swimmers with 40% of MVL.

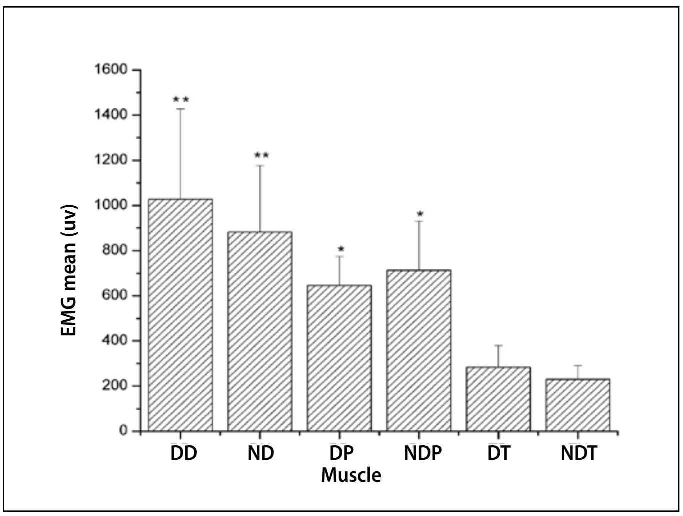

Figure 4. Values expressed in RMS (μv) of the electrical activity of the dominant deltoid (DD), non-dominant deltoid (ND), dominant pectoralis (DP), non-dominant pectoralis (NDP), dominant triceps ( ) and non-dominant triceps (NDT)muscles of the 11 swimmers with 80% of MVL.

Table 4. Values expressed in RMS (μv) of the summed median electrical activity of the dominant deltoid with the non-dominant, dominant pectoralis with the non-dominant pectoralis, dominant triceps with the non-dominant triceps muscles of the 11 swimmers with 80% of MVL.

	Muscles		
Volunteer	Deltoid	Pectoralis	Triceps
1	1.641	1.572	499
2	1.704	1.588	752
3	1.854	1.387	665
4	1.524	1.691	594
5	2.404	811	450
6	1.990	988	391
7	1.288	1.865	190
8	1.530	1.347	615
9	1.823	1.377	444
10	3.192	1.291	529
11	2.059	1.019	510
Mean/standard deviation	1.910** ± 521,7	1.358* ± 319,9	513 ± 150,2

*significance of 0.05.

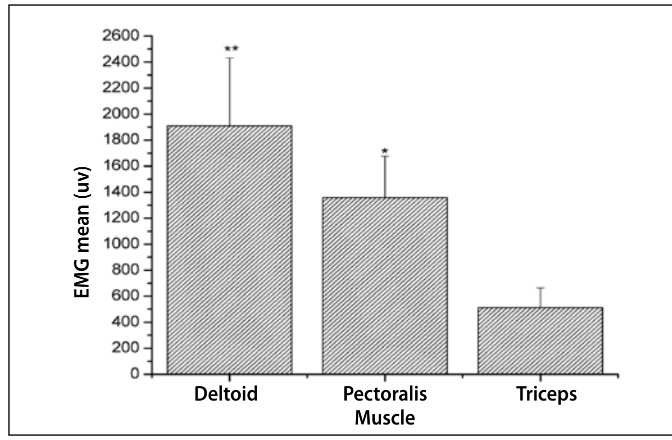

Figure 5. Values expressed in RMS (μv) of the summed electrical activity of the dominant deltoid with non-dominant deltoid, dominant pectoralis with non-dominant pectoralis and dominant triceps with non-dominant triceps muscles of the 11 swimmers with 80% of MVL.
*significance of 0.05.

DISCUSSION

The muscular activity is always expressed through the joint activity of the muscles,where it is not possible that one movement occurs due to the action of a muscle in isolation. Therefore, to evaluate or analyze muscular actions in a multiarticular exercise by the observation of the action of agonists, antagonists and synergic muscles offers an interesting parameter concerning the comparison between the activities of the dominant and non-dominant limbs both uniand bilaterally.

Our data refer to the analyses of the shoulder-press exercise, which is crucial to the physical preparation of swimmers, with aim on increase of performance. When the bilateral intermuscular activity is analyzed, the deltoid muscle presented higher activity followed by the pectoralis major and tricepsbrachii both in the test with 40% and 80% of MVL. It is clear that the exercise studied can guarantee neural adaptations derived from the training applied to swimming, since it activates important swimming synergists, since the sport demands shoulder movements in arm circle movements above the head line[15].

The findings by Bankoffand Vitti[10]andVittiand Bankoff[9]support ours, since they studied swimmers of different categories simulating unilateral exercises of backstroke and crawl styles approaching the participation of the pectoralis major and latissimusdorsimuscles among other muscles. Generally speaking, the pectoralismajor muscle showed high electromyographic activity during the swimming practice of the backstroke and crawl styles of the individuals, either trained or not, being the signs concerning the trained categories more intense.

Our data agree with the ones by Kronberg*et al.*[16], Campos *et al.*[17]and Oliveira *et al.*[7], who reported that the medial and anterior portions of the deltoid muscle play an important role in the arm abduction and that the EMG increase is proportional to the increase of the range of motion.

The significant increase in the electrical activity of the deltoid medial, pectoralis major (clavicular portion) and triceps brachii (long head) became evident in our study with 80% when compared 40% load of the MVL.

When using loads of 40% of MVL, the deltoid muscle acted with 63.3% of the EMG activity, the pectoralis major muscle 24%, and the triceps brachii12.6%. When the 40% load is doubled to 80% of MVL, the deltoid muscle decreased its relative participation to 50%

of the EMG activity, followed by the pectoralis and triceps muscles to relative increase of 36% and 14%, respectively. The significant increase of the EMG activity of the pectoralis major muscles with 80% load may have decreased the production of relative recruiting strength that the deltoid medial muscle (primary motor) may generate; however, such increase may be a protection mechanism of the glenohumeral joint against possible injuries, occurring hence higher inter and intramuscular strength distribution between the synergist, antagonist and stabilizer muscles.

In studies performed by Duarte Cintraand Furlani[18] concerned with uni and multiarticular exercises for lower limb, they verified that the increase in weight during the movements caused high level of activity and simultaneous contraction of all the studied muscles. Despite the impossibility of direct comparison, this statement is in agreement with our findings, since when the load factor in isolation is analyzed it was verified that the muscles analyzed presented higher electrical activity when the load was doubled from 40% to 80% of MVL.

The increase in muscular strength was possibly determined by the development of the adaptation alterations at the level of the central nervous system which led to the intensification of the motor centers capacity to recruit a large number of motor neurons, which were deactivated before, increasing the number of motor units which participated in the muscular contraction. This results is in agreement with the theory of muscular strength grading, which highlights that if there is simultaneous activation of a higher number of motor units, increase of muscular strength will occur as well, evidenced in the present study when 80% of MVL was used[19].

For training purposes, this situation is favorable, since the muscle should act against some resistance it usually does not find so that the physiological alterations which result in the expected training effects can occur[14].

Tassi*et al.*[20], analyzed the bilateral behavior of a thigh muscle, and contrary to our findings, they verified Strong potential of the dominant limb over the non-dominant one. In these authors' opinion, the dominant limb is more demanded in daily situations, and it is also believed that the right muscles in right-handed individuals present considerable development compared to the left-handed ones, and hence, contribute to the anatomic and functional asymmetry.

In our findings, when the myoelectric activity of the dominant and non-dominant limb is compared, it was visible that both presented similar electrical activities, except for the triceps brachii muscle, with 80% of the MVL. The resistance exercises correctly performed with individualized loads, adequate posture and guidance from a professional, can with the trainig progress, improve the recruiting pattern of the motor units (coordination), eliminating the diferences between the muscular contractions of opposite sides by the effect of transference (crossed education) mentioned by Moritaniand De Vries[21], Sale[22], Shi Zhou[23], Simão *et al.*[24]and Brentano and Pinto[25].

The prescription of uniarticular and multiarticular resistance exercises bilaterally performed for training helps in the development of the physical preparation of swimmers in and out the water. It became evident that the loads increase in a multiarticular exercise really boosts muscular activation through the increase of the neural drive with no significant compromising of the intermuscular coordination of the synergists, offering safety for the athlete in his training routine.

CONCLUSION

The results presented added to the methodology used in this research let us conclude that in practical terms of neuromuscular training practical prescription and periodization, the bilateral contractions performed in the multi-articulated joint shoulder-press convergent machine are efficient in recruiting (80% > 40%) the deltoid medialis, pectoralis major (clavicular portion) and triceps brachii (long head) muscles, being differences between the dominant and non-dominant limbs only for the dominant triceps brachii with load of 80% of MVL in these swimming athletes with eight training history.

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All authors have declared there is not any potential conflict of interests concerning this article.

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