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ORIGINAL ARTICLE

Upper body force production after a low-volume static and dynamic stretching

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Abstract

This study investigated the acute effect of a low-volume static and dynamic stretching on maximal isometric peak force (MIPF), time to maximal isometric force (TMIF), rate of force production (RFP) and average amplitude of the surface EMG (AvgEMG) of the main agonist muscles acting on the bench press maximum isometric force exercise. Thirty subjects were randomly divided into three groups: static stretch (SG: 22.8 ± 5.6 years, 176.6 ± 3.5 cm, 74.4 ± 5.9 kg), dynamic stretch (DG: 21.4 ± 3.9 years, 178.4 ± 7.2 cm, 71.7 ± 8.2 kg) and control group (CG: 20.4 ± 3.6 years, 179.8 ± 5.8 cm, 74.4 ± 9.8 kg). SG performed two 30-s repetitions and DG performed 10 repetitions of each of the two different exercises for the pectoralis major and triceps brachii. The MIPF, TMIF, RFP and AvgEMG of the pectoralis major (sternocostal part) and triceps brachii (long and lateral head) were measured before and immediately after the stretching protocols. A significant decrease in the MIPF from pre- to post-stretching was observed in both SG ($p < 0.001$) and DG ($p < 0.05$). No significant differences were found in the CG for all force parameters. No significant differences in the TMIF and RFP from pre- to post-stretching were found in the three groups. The SG showed a significant ($p < 0.05$) decrease in the AvgEMG of the three muscles, whereas no significant differences were found for the DG and CG. These findings suggest that a low-volume static and dynamic stretching adversely affects efforts of muscle maximal strength of the upper limb muscles studied, but it does not seem to affect TMIF or RFP.

Keywords: *Warm-up, power, maximal force, electromyography, bench press exercise*

Introduction

Recent research has questioned the importance of stretching procedures as a warm-up before strength and power activities (Avela, Kyröläinen, & Komi, 1999; Fowles, Sale, & MacDougall, 2000; Gergley, 2009; Little & Williams, 2006; McMillian, Moore, Hatler, & Taylor, 2006; Young, Elias, & Power, 2006). Previous studies have shown that performing static stretching decreases several muscular performance variables, in different age populations, in both sexes and in different tasks (Behm et al., 2006; Cornwell, Nelson, & Sidaway, 2002; Fowles et al., 2000; Kokkonen, Nelson, & Cornwell, 1998; Little & Williams, 2006; Morse, Degens, Seynnes, Maganaris, & Jones, 2007; Ryan et al., 2008; Vetter, 2007; Weir, Tingley, & Elder, 2005; Young et al., 2006). Despite these suggestions, it is still common among athletes and coaches to include stretching exercises at the beginning of a strength training session, believing that this practice will reduce the risk of injury and improve the performance (Judge, Craig, Baudendistal, & Bodey, 2009).

Mechanical and neural mechanisms have been considered by different researchers to explain the acute effects of static stretching on the muscle performance (Abellaneda, Guissard, & Duchateau, 2009; Cornwell et al., 2002; Evetovich, Nauman, Conley, & Todd, 2003; Hough, Ross, & Howatson, 2009; Morse et al., 2007; Ryan et al., 2008; Weir et al., 2005).

Viscoelastic stress relaxation is a well-known mechanical effect induced by static stretching

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(McHugh, Magnusson, Gleim, & Nicholas, 1992). This effect suggests the occurrence of both mechanical and structural tissue alterations (i.e. passive muscle stiffness reduction) that may affect muscle–tendon complex force transmission and consequently induce a loss in muscle force production and output (Cornwell et al., 2002; Evetovich et al., 2003; Moran, McGrath, Marshall, & Wallace, 2009; Ryan et al., 2008; Weir et al., 2005). On the other hand, some researchers have suggested that a reduction in motoneuron pool excitability, through a lower EMG activity, may explain stretch-induced decrements in the muscle performance (Hough et al., 2009). Other researchers have connected this reduction to the changes in the afferent drive, and consequential decrease in muscle spindles sensitivity, increase in nociceptors activation as well as reduction in the activation of Golgi tendon organs (Avela et al., 1999).

Since a static stretching prior to strength and power tasks appears to induce negative performance effects, different researchers have suggested the use of the dynamic stretching. The studies conducted by these authors have shown not only that performing dynamic stretching before strength and power activities does not negatively affect performance but also that it can be related with the improvement of some lower body physical skills (Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; Fletcher & Anness, 2007; McMillian et al., 2006; Yamaguchi & Ishii, 2005; Yamaguchi, Ishii, Yamanaka, & Yasuda, 2007).

However, these studies have mainly examined the effects of stretching on lower body performance, with few exceptions concerning the effects of static stretching on upper body muscles (Evetovich et al., 2003; Gergley, 2009; Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004; Moran et al., 2009; Torres et al., 2008). However, Evetovich et al. (2003) reflected a negative effect of static stretching on the strength production of the biceps brachii. Gergley (2009) has found a depressing effect in some golf performance variables. In spite of this, three other studies involving upper limb movements did not find any negative effect induced by previous static stretching. Knudson et al. (2004) did not observe any change in ball velocity due to static stretching before a tennis serve. Moran et al. (2009) have found no effect of static stretching in a golf swing performance compared with the 'no-stretching' condition. Similar results were observed by Torres et al. (2008) in the performance of maximal force production and power tasks, such as the bench press exercise and medicine ball throwing. There is, however, a lack of studies on the effects of static and dynamic stretching in upper body activities.

The purpose of this study was to investigate the acute effect of low-volume static and dynamic stretching on maximal isometric peak force (MIPF), time to maximal isometric force (TMIF), rate of force production (RFP) and EMG amplitude of the main agonist muscles involved in the bench press exercise during a maximum voluntary isometric contraction (MVIC). We hypothesised that a low-volume static stretching would decrease the strength and power muscle performance and low-volume dynamic stretching would have no effect.

Methods

Experimental approach to the problem

A repeated measures study design was used to determine and compare the maximal isometric force, time to maximal isometric force RFP and EMG amplitude of the main agonist muscles involved in the bench press exercise before and after a low-volume static and dynamic stretching.

Subjects

Young, active male subjects ($n = 30$) studying in colleges volunteered for this study. All subjects gave written informed consent. This study was approved by the Research Ethics Committee of the Faculty of Human Kinetics for the use of human subjects in the research. Participants were randomly divided into three equivalent groups: static stretch (SG), dynamic stretch (DG) and control group (CG). The anthropometric characteristics of each group are described in Table I. The groups were similar in age, height and weight ($p > 0.05$).

Procedures

Stretching intervention. Static stretching consisted of a slow passive manoeuvre until a maximum range of motion was attained, in a position in which subjects reported a feeling of maximal stretch but no discomfort or pain. The SG performed two 30-s repetitions, with a 15-s rest period between repetitions, for each of the two different stretching

Table I. Anthropometric characteristics of each group

Groups	Age (years)	Height (cm)	Weight (kg)
SG	22.8 ± 5.6	176.6 ± 3.5	74.4 ± 5.9
DG	21.4 ± 3.9	178.4 ± 7.2	71.7 ± 8.2
CG	20.4 ± 3.6	179.8 ± 5.8	74.4 ± 9.8

Note: ANOVA: There is no significant difference in anthropometric characteristics between groups (Age – $p = 0.475$; Height – $p = 0.451$; Weight – $p = 0.702$).
SG, static group; DG, dynamic group; CG, control group.

exercises targeting the pectoralis major and triceps brachii (**randomized order)**. For the pectoralis major muscle, the subjects were sitting on a bench with their hands behind their head. The partners who were positioned at the back of the subjects moved the elbows simultaneously to stretch the pectoralis major. For the triceps brachii muscle, the subjects flexed their arms and forearms and moved their hands towards the scapula. With the opposite hand, they grasped the elbow and pulled it behind the head to increase the arm flexion.

The dynamic stretching consisted of moving the limbs actively with a controlled slow–moderate velocity until maximum range of motion. The DG performed 10 repetitions of 6 s each (3 s in the ascendant phase and 3 s in the descendent phase), for each of the two different stretching exercises targeting the pectoralis major and the triceps brachii. For the pectoralis major muscle, the subjects were sitting on a bench, with the trunk flexed over their thighs and the arms suspended. In this position, a horizontal abduction was performed maintaining the arm abducted at 90 degrees, moving the elbows towards the upper back and returning to the initial position. For the triceps brachii muscle, the subjects started in a position with the shoulder joint flexed at 90 degrees keeping their elbows extended, parallel to the floor. Then, the subjects performed elbow and shoulder joint flexion simultaneously to stretch the three portions of the triceps brachii. After reaching a maximum shoulder joint and elbow flexion, they returned their limbs to the initial position.

Experimental design. After arriving at the laboratory, anthropometric measurements were performed. Then, before strength activities, there was a brief familiarization with the protocol apparatus (i.e. bench press exercise), following a 5-min warm-up (i.e. submaximal intensity on a rowing ergometer). After this, a maximal voluntary isometric contraction (MVIC) was completed using the bench press exercise with the elbow flexed and the shoulder joint abducted at 90 degrees, before and immediately after the stretching (SG and DG) and non-stretching (CG) protocols. Each subject completed two MVIC trials, with the duration of 3–4 s each and a 60-s rest period between trials. All subjects were instructed to produce force as fast as possible for all MVIC. The trial with the highest MVIC value was used for subsequent analysis.

Force and EMG data collecting and processing. All isometric force data were obtained from a multipower machine having force sensors. Signals were A/D converted (MP100 – Biopac™ Systems, Inc., Santa Barbara, CA, USA) with a sample rate of 1000 Hz. The force–time curve was determined and analysed using the Acknowledge™ software (Biopac™ Systems, Inc., Santa Barbara, CA, USA). The MIPF was established in the force–time curve as the point where the maximum force was reached. The instant in which the curve reaches 20 N was used to indicate the beginning of the force production and to measure the TMIF. The RFP was determined by the maximum slope of the derivative of the force–time curve during the first 250 ms after the beginning of the force production.

Surface active bipolar electrodes (Analog Devices mod. AD620, gain of $1000 \pm 2\%$) were placed (20 mm centre to centre) over the mid-portion of each muscle: triceps brachii (long head) – the electrodes were placed at 50% on the line between the posterior crista of the acromion and the olecranon at two-finger widths medial to the line; triceps brachii (lateral head) – the electrodes were placed at 50% on the line between the posterior crista of the acromion and the olecranon at two-finger widths lateral to the line (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000); pectoralis major (sternocostal part) – the electrodes were placed just medial to the anterior axillary fold over the bulk of the muscle (Leis & Trapani, 2000). The average amplitude of the surface EMG (AvgEMG) of the triceps brachii (long and lateral head) and the pectoralis major (sternocostal part) was measured during all MVIC. The ground electrode was fixed on the clavicle. Alcohol and a razor were used for cleaning the areas. In order to minimize a possible interference, all EMG procedures were in accordance with the International Society of Electrophysiology and Kinesiology (ISEK, 1999) recommendations.

The EMG signals were amplified (input impedance = 5 MΩ; bandpass filters = 10–500 Hz; CMRR > 80 dB) and A/D converted (MP100 – Biopac™ Systems, 16 bits) with a sample rate of 1000 Hz. Once the EMG data were recorded, and after visual inspection, the raw EMG signals were digitally band-pass filtered (20–500 Hz), full-wave rectified, low-pass filtered with a Butterworth second order and a frequency cut-off of 30 Hz, and amplitude normalized using the EMG of the first MVIC as reference. The AvgEMG signal was measured during a window of 20 ms. For data processing, automatic routines using the MATLAB® v7.0 software (The Mathworks Inc., Natick, MA, USA) were developed and used.

Statistical analysis

Statistical analysis was performed using the SPSS, version 15.0 (SPSS Inc., Chicago, IL, USA). To guarantee that the three groups were identical in terms of anthropometric characteristics, the one-way analysis of variance (ANOVA) was conducted for

Table II. Maximal isometric peak force (MIPF), time to maximal isometric force (TMIF) and rate of force production (RFP) values before (pre) and immediately after (post) the stretching protocols

	MIPF (N)		TMIF (ms)		RFP (N/s)	
Groups	Pre	Post	Pre	Post	Pre	Post
SG	895.7 ± 232.1	839.9 ± 213.8[a]	1339.6 ± 689.1	1149.9 ± 519.2	7205.5 ± 2451.4	7874.1 ± 2345.5
DG	762.0 ± 155.4	734.6 ± 136.6[b]	1387.3 ± 429.1	1446.2 ± 531.7	7469.0 ± 2203.8	6956.5 ± 2865.6
CG	814.9 ± 112.5	809.5 ± 117.3	1346.2 ± 378.1	1265.2 ± 617.3	7797.6 ± 2897.6	8050.1 ± 2482.4

[a]Denotes significant difference between pre- and post-stretching intervention ($p < 0.001$).
[b]Denotes significant difference between pre- and post-stretching intervention ($p < 0.05$).
SG, static group; DG, dynamic group; CG, control group.

age, height and weight. Mean values and standard deviations were calculated for each parameter. To examine differences between the dependent variables measured before and immediately after the stretching protocol, the paired 't' test was used. Data normality was tested through the Shapiro–Wilk test. When normality was not found, the non-parametric Wilcoxon test was used. Normality was not found in the SG for TMIF and RFP, in the DG for the AvgEMG of pectoralis major and in the CG for TMIF and AvgEMG of pectoralis major and long head of triceps brachii. So, for those parameters, the Wilcoxon test was used instead of the paired 't' test. The effect size between the groups was calculated for maximal isometric force using Cohen's d value.

For all statistical tests, the 0.05 probability was accepted as the criterion for statistical significance ($p < 0.05$).

Results

Isometric force parameters

Table II displays the mean values and standard deviation of the force parameters of the three groups before and immediately after the stretching protocols. In the static stretch group, there was a significant decrease ($p < 0.001$) in the maximal isometric force from pre- to post-stretching. There was a decrease of nearly 6% with an initial average value of 895.7 ± 232.1 N achieving 839.9 ± 213.8 N immediately after stretching. In this group, there were no significant differences in the TMIF and RFP from pre- to post-stretching. In the dynamic stretch group, there was a significant decrease ($p < 0.05$) in the maximal isometric force from pre- to post-stretching. There was a decrease of nearly 4%, from an initial value of 762.0 ± 155.4 N to a value of 734.6 ± 136.6 N immediately after stretching. There were no significant differences in the TMIF and RFP between pre- and post-stretching. No significant differences were found in the control group for all force parameters between pre- and post-stretching. The effect size of maximal isometric force between groups showed large (0.72 – SG/CG; 0.86 – SG/DG) and moderate effects (0.47 – DG/CG).

Average EMG

Table III shows the mean values and standard deviation of the absolute and normalized average EMG of the three muscles studied, that is, pectoralis major (sternocostal part) and triceps brachii (long and lateral head) in the bench press performed before and immediately after the stretching protocols. The subjects of the DG did not show any significant differences. No significant differences were found in the average EMG measured for the control group. On the other hand, the static stretch group showed significant ($p < 0.05$) decreases in the average EMG of the three muscles from pre- to post-

Table III. Average amplitude of the EMG before and immediately after the stretching protocols

		Pectoralis major		TB long head		TB lateral head	
Groups		Pre	Post	Pre	Post	Pre	Post
SG	mV	0.041 ± 0.034	0.034 ± 0.028[a]	0.056 ± 0.031	0.047 ± 0.031[a]	0.141 ± 0.095	0.127 ± 0.084[a]
	%	100 ± 0.0	83.64 ± 69.25[a]	100 ± 0.0	82.69 ± 55.14	100 ± 0.0	90.56 ± 50.50[a]
DG	mV	0.042 ± 0.026	0.037 ± 0.017	0.060 ± 0.028	0.058 ± 0.024	0.147 ± 0.059	0.136 ± 0.055
	%	100 ± 0.0	88.52 ± 41.24	100 ± 0.0	96.74 ± 40.20	100 ± 0.0	92.70 ± 37.53
CG	mV	0.043 ± 0.029	0.038 ± 0.023	0.050 ± 0.029	0.048 ± 0.023	0.071 ± 0.065	0.073 ± 0.061
	%	100 ± 0.0	88.86 ± 53.75	100 ± 0.0	96.15 ± 45.90	100 ± 0.0	102.69 ± 85.28

Note: The average EMG is represented in terms of absolute and percentage values.
[a]Denotes significant difference between pre- and post-stretching intervention ($p < 0.05$).
SG, static group; DG, dynamic group; CG, control group.

stretching. Considering that the average EMG recorded before the stretch protocols was defined as 100%, the pectoralis major muscle presented a decrease of 16.4%, the long head of the triceps brachii 17.4% and the lateral head 9.5%.

Discussion

The results of the present study indicate that the low-volume static and dynamic stretching has the ability to adversely affect the efforts of maximal strength dependence of upper limb muscles involved in the bench press exercise. The MIPF decreased in both stretching groups. In the control group, no changes were found in the MIPF between the pre- and post-events.

The force velocity is very important when we need to develop force rapidly and at high velocities, which is very common in sport activities. Concerning force parameters related to force velocity, we measured TMIF and RFP. RFP was the rate of force measured during the first 250 ms after the beginning of force production. The RFP is more dependent on the initiation of force, for example, the ability to produce a high-level force at the beginning of a muscular contraction, and is more sensitive to the starting strength. TMIF measured the time interval between the force production onset and the instance of peak force. It is influenced by the RFP, and it is also dependent on the maximum value of absolute force. Our results show that there was no short-term effect of static or dynamic stretching on TMIF and RFP.

The results of the SG are consistent with those of Evetovich et al. (2003) and Gergley (2009) studies, in which a negative effect induced by static stretching in upper body tasks in the maximal external force produced was found. Also, SG results are in conformity with three other studies that have not found any effect of static stretching in upper body tasks which implies velocity production (Knudson et al., 2004; Moran et al., 2009; Ryan et al., 2008). The negative effects induced by static stretching in upper body tasks may be flexibility profile dependent, since the stiffness of the tissues being stretched on all subjects was not controlled in all these studies. Furthermore, there are studies indicating that the negative effects are related to muscle structural changes (Cornwell et al., 2002; Evetovich et al., 2003; Ryan et al., 2008; Weir et al., 2005). Thus, it is possible that subjects with higher stiffness indexes will respond less to the negative effects induced by static stretching. Future studies should address this. Regarding the effects of dynamic stretching, the results of DG do not agree with previous studies (Faigenbaum et al., 2005; Fletcher & Anness, 2007; McMillian et al., 2006; Yamaguchi & Ishii, 2005; Yamaguchi et al., 2007). This is an interesting finding, since previous studies have shown that dynamic stretching does not reduce and may, in certain circumstances, improve the performance (Faigenbaum et al., 2005; Fletcher & Anness, 2007; McMillian et al., 2006; Moran et al., 2009; Yamaguchi & Ishii, 2005; Yamaguchi et al., 2007).

The mechanisms underlying the strength reduction are unknown. However, they seem to be different for each stretching regime. The decrease of MIPF in the DG does not appear to be caused by the reduction in muscle activation. No significant changes were observed in the EMG signal amplitude of three important muscles acting on the arm (i.e. pectoralis major) and forearm movements (i.e. long head and vastus lateralis of triceps brachii) during the bench press exercise for the DG. This suggests that the excitability of the motoneuron pools of these muscles did not diminish, and that the motor unit recruitment and firing frequency was not affected. On the other hand, the decrease in the EMG amplitude of the three muscles studied found in the SG suggests that the reduction in muscle activation can be a part of the explanation for the reduction in strength performance. However, the EMG amplitude reduction was not observed in the study of Evetovich et al. (2003) that has verified a negative effect induced by static stretching.

It should be noted that low static and dynamic volume was used, unlike in some previous research about acute effects of stretching (Fowles et al., 2000). These are similar to the volumes usually performed in the sport practice. The static stretching routine for each muscle was composed of two sets of 30 s with a total stretching volume of 1 min. The dynamic stretch group performed 10 repetitions with a slow-to-moderate velocity, for each of the two different dynamic stretching exercises, resulting in a total set duration of 60 s.

The findings of this research should be carefully considered based on their limitations. The muscles involved in the experimental stretching groups may have been stretched with different volume and intensity levels, because it is difficult to determine an equal stretching intensity and volume for the static and dynamic regime. The fact that the familiarization procedures were done in the same day than the strength tests may have influenced the results. Also, the physical condition of the subjects was not controlled, especially the stiffness of the tissues which regulate their flexibility profiles. This may have predisposed the results as well.

Additionally, the study design may have prejudiced the results, since it is not a within-study design. Subjects with different physical characteristics may respond differently to the stretching stimulus. A counter-balanced design would probably be the best methodology for this study. However, a within-group design has the advantage of being applied in a training context. In a training situation, subjects are not often exposed to two consecutive conditions. In a normal athletic training situation, some athletes do a type of training and others do otherwise.

It is not easy for clinicians/coaches to apply the same stimulus in two different conditions and then compare the outcome. It is easier to compare between two experimental conditions. Nevertheless, this mode is not the most effective set to conclude in scientific terms.

Physical education teachers, trainers, therapists, physicians and athletes should be careful when deciding to use stretching routines in the warm-up before motor skills that depend on maximal strength. In this study, the participants who were subject to low volume stretching for the pectoralis major and the triceps brachii muscles decreased the maximal isometric force (i.e. the maximum force exerted against an immovable bar) in the bench press exercise. These negative effects were observed in either static or dynamic stretching.

Thus, our results suggest that a low-volume static or slow-to-moderate dynamic stretching of the pectoralis major and triceps brachii should be avoided when the goal is to produce maximal isometric force in the bench press exercise. In spite of the small magnitude of changes in the isometric force that we found, 4% and 6%, respectively, after static and dynamic stretch, these changes could be decisive in sport contexts where athletes must perform the highest levels of force. Nevertheless, when the goal is to achieve the highest RFP or the TMIF, previous stretching procedures are less important, since they seem not to affect in the same way.

In conclusion, the results of the present study indicate that static and slow-to-moderate dynamic stretching negatively affects maximal isometric force production in the bench press. The mechanism behind this effect seems to be different for each stretching regime. We recommend that future research should test the effects of static and dynamic stretching in subjects with different flexibility profiles.

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