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INFLUENCE OF STATIC STRETCHING DURATION ON QUADRICEPS FORCE DEVELOPMENT AND ELETROMYOGRAPHIC ACTIVITY

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ABSTRACT

Purpose. The purpose of the present study was to analyze the influence of static stretching duration on quadriceps muscle isometric force and electromyographic (EMG) activity of the *rectus femoris* and *vastus lateralis*. **Basic procedures.** Twenty recreationally-active healthy men were selected for the study. On two separate days, participants took part in two stretching protocols of different durations. Following a specific warm-up, participants performed isometric strength assessments of the dominant leg before and after a bout of quadriceps stretching. The stretching protocol consisted of two stretches for the quadriceps muscle for three repetitions of 30 seconds on one visit, and 60 seconds on the other. **Main findings.** The results revealed a significant reduction in quadriceps muscle mean and peak forces and EMG activity for the *rectus femoris* with both 30- and 60-second stretching protocols ($p \leq 05$). However, EMG activity of the *vastus lateralis* decreased significantly only in the 60-second protocol ($p \leq 05$). **Conclusions.** Both stretching protocols induced significant decreases in strength and EMG activity, although the stretching duration (60×30) did not appear to be a major influencing factor for the current strength reductions. In this perspective, coaches and athletes should avoid flexibility training which consists in stretching repetitions of 30 seconds or longer prior to competitions.

Key words: stretching, force, peak force, isometric, electromyography

Introduction

Stretching is commonly performed in sports due to its effectiveness in the maintenance and improvement of joint range of motion. Strength and conditioning professionals, coaches, athletic trainers, and physical therapists recommend stretching prior to competition or a strenuous activity because of the common belief that it can improve athletic performance and/or reduce the risk of musculoskeletal injuries [1].

Recent studies have suggested static stretching performed before an exercise can temporarily compromise the muscle's ability to produce force [2–7] and reduce the electromyographic (EMG) activity of the muscle [5, 6]. Conversely, other studies have not reported significant performance decrements following static stretching on vertical jump [8], eccentric peak torque [9], concentric peak torque and muscular power in elite athletes [10], dynamic balance [3], tennis serve [11] and kicking performance [12], and the hamstrings-to-quadriceps (H:Q) ratio during maximal concentric isokinetic muscle actions [13].

Avela et al. [2] and Fowles et al. [14] found significant reductions in strength and EMG activity of the plantarflexor muscles after an hour of fast and repeated stretching and with a protocol of 13 repetitions of 135 seconds, respectively. Likewise, Weir et al. [15] reported similar results using a stretching protocol of 5 repetitions of 120 seconds in plantarflexor muscles. However, Behm et al. [16] reported that static stretching for periods of 45 seconds did not cause significant differences in strength, despite the findings of a decrease in balance performance along with increases in reaction time and movement time. Similarly, Alpkaya and Koceja [17] found no significant changes using 15 seconds of stretching, in which there were no positive or negative effects on reaction time or explosive force.

Ogura et al. [18] reported a significant decrease in knee flexor muscle strength using 60 seconds of stretching. However, no decreases in strength were found for a 30-second stretch duration. In addition, when com-

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paring four different stretching periods of 10, 20, 30 and 60 seconds, Siatras et al. [7] revealed peak force decreased only with the 30- and 60-second stretch repetitions. Thus, there may be a direct relationship between the stretch duration and stretching-induced decreases in performance. Conversely, these data are not in agreement with the findings of Brandenburg, who reported that both 15 and 30 seconds of stretching caused decreases in hamstrings strength, although there were no significant differences between these stretching durations [19].

To our knowledge, only one study has examined the effects of different durations of static stretching on EMG activity [20]. However, we are unaware of this type of study for the quadriceps muscle, which is an important knee extensor and has a role in sports requiring jump, kicks, and running. Otherwise, most of studies that found decreases in strength after static stretching used longer durations allowing some controversy regarding short duration stretching on performance impairment.

In this context, the present study aimed to investigate the acute influence of static stretching durations of 30 and 60 seconds, commonly recommended for warm-up [18], on isometric force of the quadriceps muscle and EMG activity of the *rectus femoris* (RF) and *vastus lateralis* (VL) muscles in young recreationally-active healthy males. We hypothesize that the longer stretching would be able to cause a greater decrease in muscle strength and EMG activity.

Material and methods

Subjects

The sample consisted of 20 males (22 ± 3 years; 174 ± 6 cm; 72.4 ± 11.4 kg; 23 ± 3 Kg/m^2; 19.1 ± 5.3%). The study inclusion criteria had the following characteristics: a) all the subjects were physically active, but not athletes, and had not taken part in a formal structured flexibility or strength training program during the previous 12 months; b) did not perform any type of exercise activity for 48 hours prior to the strength assessments; c) participants could not have any functional limitations for the flexibility training or the performance of the isometric strength test; and d) did not present any medical condition that could influence the collection or interpretation of the data. After informing subjects of the testing and training procedures to be performed during the study, all participants read and signed an informed consent form approved by the Human Subjects Institutional Review Board. This study was approved by the Ethics Committee.

Experimental design

Experiment layout

A randomized, pre-experimental repeated measures (pre- vs. post-stretching) cross-over design was used to investigate the acute effects of quadriceps static stretching duration on knee extension strength and EMG activity. All subjects performed two protocols of static stretching (30 and 60 seconds) on two separate days with an interval of 48 hours between testing sessions (Fig. 1). All procedures were carried out on the same time of day and in a controlled environment with temperature between 23°C and 25°C.

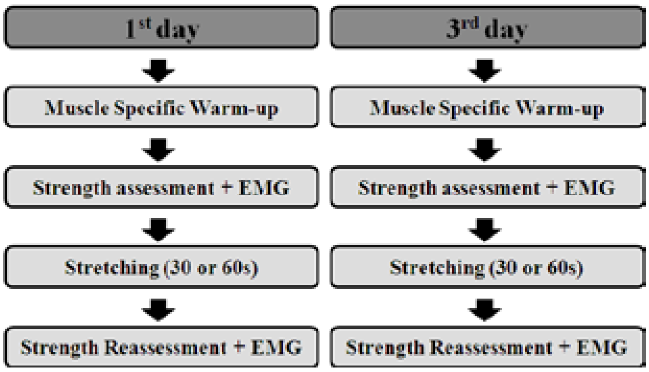

Figure 1. Experimental design with a 48-hour interval between testing sessions

Measurements

Strength assessments were performed using a Knee Extension Machine, adjusted to fit individual anthropometric characteristics, adapted with thoracic and abdominal stabilization strips. Once the subjects were positioned appropriately, a specific warm-up of the quadriceps muscle of the dominant leg was performed, following the recommendation of the American College of Sports Medicine [21], which advocates warming-up prior to any type of physical activity. The load was set at 10% of total body mass and consisted of 3 sets of 10 repetitions performed in a dynamic knee extension apparatus.

The warm-up was immediately followed by a rest period of 2 minutes. After the warm up and rest period, a maximum isometric voluntary contraction (MIVC) of the knee extensors was tested, lasting 10 seconds. Subjects were positioned at 70° of static knee flexion (0° = full knee extension). Surface EMG signal was collected for the RF and VL simultaneously with the strength assessment. During testing, participants were instructed to keep both arms crossed over the chest in order to ensure consistency and optimal movement performance. The MIVC (r = 0.92) tests revealed high intra-class correlation coefficients, respectively while paired t-tests demonstrated no significant difference.

The mean strength of the MVIC (mean of MIVC) and peak force (PF) were identified by the load cell signal. The mean MIVC, PF, and EMG signal of RF and VL were analyzed in pre- and post-stretch of two different stretching durations (30 and 60 seconds) separately. To compare the influence of two different stretching durations, EMG values were normalized to the pre-stretching values.

Stretching protocols

Two different stretches were performed for the quadriceps muscle based on previous research [4, 6, 9]. Each stretch was repeated three times lasting 30 or 60 seconds depending on the condition for that particular day. In the first stretching exercise, the subject remained standing and in the second exercise, the subject laid in a prone position. In both stretches, the same investigator performed a passive unilateral (dominant leg) knee flexion and a hip extension on the subject, with one hand on the ankle causing a knee flexion and the other hand was holding the knee, forcing a hip extension. A 20-second rest interval between each repetition was provided. The total mean duration for the entire stretching procedure was 4.1 ± 1.3 min (mean + SD) using the 30-second protocol and 8.1 ± 1.4 min using the 60-second protocol.

During the stretching protocol, the targeted limb was moved slowly until a mild discomfort was acknowledged by the subject, who was instructed to relax while the stretched position was maintained for 30 or 60 seconds depending on which stretching intervention was being performed. Immediately after the stretching (~ 1 min), EMG signal and quadriceps MVIC were collected again, using the same methods as the pre-stretching assessment. Since the main objective was to examine the acute effects of stretching on the strength and EMG activity, flexibility (i.e. range of motion) was not assessed before and particularly after the stretching protocol to avoid increasing the time elapsed between stretching and strength assessments. All procedures and measurements were carried out by two trained investigators. In order to minimize bias and maintain consistency, the anthropometric data were evaluated by a single examiner and stretching procedures were conducted by the same investigator.

Equipment and analysis

A load cell (EMG System, São Paulo, Brazil) was used to capture the maximal isometric voluntary contraction. The EMG signals were acquired using an 8-channel electromyography equipment (EMG System, São Paulo, Brazil), consisting of a signal conditioner with a band pass filter with cut-off frequencies at 20 – 500 Hz, an amplifier gain of 2000x, and a common mode rejection ratio > 120 dB. All data were processed using specific software for acquisition and analysis (AqData5 for Windows®, Ohio, USA), a converting plate for A/D 12 bits signal to convert analog to digital signals with a sampling frequency of anti-aliasing 2.0 kHz for each channel, and an input range of 5 mV. Pre-amplified bipolar superficial electrodes of Ag/AgCl (MEDITRACE®, USA) with an interelectrode (center-to-center) distance of 20 mm were used. The EMG signal was full wave rectified and the electrical activity was measured using the root mean square (RMS) values.

In order to achieve an optimal EMG signal and low impedance (< 5 kΩ), two 4 cm^2 areas of skin were shaved, abraded, and cleaned, as recommended by the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations [22].

Electrodes were fastened to the skin guided by bone prominences [22]. The electrodes of the RF muscle were placed at 50% of the distance between the anterior superior iliac spine and the superior border of the patella. For the VL, the electrode was placed at the 66% distal distance between the anterior superior iliac spine and the side border of the patella. The anatomical reference method is recommended by SENIAM [22], in order to avoid the innervated zones and reduce the influence of cross-talk. As data were collected on different days, the exact positions of the electrodes were marked with a dermographic pen, and electrodes placed in such a manner as to prevent artifacts resulting from the electrode sliding during the muscle actions. In all procedures, the recording and analysis of EMG signals were carried out as recommend by the International Society of Electrophysiology Kinesiology (ISEK) [23].

Statistical analysis

All EMG data (VL and RF) were normalized to the pre-test values. A test for normality of the EMG activity and strength data using the Shapiro-Wilk tests yielded significant evidence of normality. Three separate multi-factor two-way ANOVAs were used to identify the interaction in muscle × time intervention for strength and normalized EMG values. When necessary, post-hoc paired t-tests were used to compare pre- and post-stretching strength and EMG activity for the two stretching durations (30 and 60 seconds) separately. All statistical procedures were carried out with a significance level of $p \leq 0.05$.

Results

The results of MVIC mean and PF before and after stretching are shown in Figures 2 and 3, respectively. Changes in mean and PF were observed with both stretching protocols. Mean of MVIC decreased by 6% and 9%, in the 30- and 60-second durations, respectively ($p \leq 0.05$). Likewise, PF also decreased by 4% and 8% after 30 and 60 seconds of stretching, respectively ($p \leq 0.05$).

The average EMG values (RMS) of the RF were significantly reduced after stretching with both the 30- and 60-second protocols (Fig. 4). However, VL mean EMG (RMS) was significantly reduced only after 60 seconds of static stretching (Fig. 5).

A comparison of the normalized values of strength and mean EMG (RMS) for both stretching durations is shown in Table 1. No differences were identified in

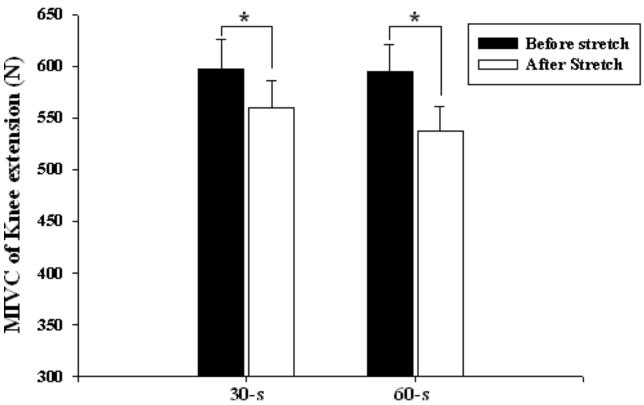

Figure 2. Mean of knee extension MIVC before and after static stretching for 30 ($n = 20$) and 60 seconds ($n = 20$). (*) Significant difference from pre- to post-stretching ($p < 0.05$)

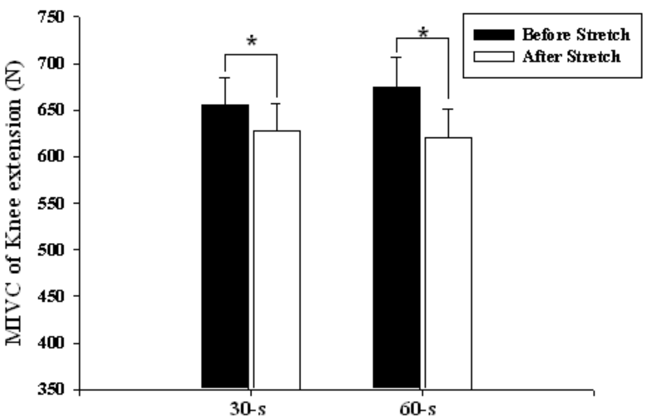

Figure 3. Peak force of knee extension maximal voluntary isometric force (MVIC) before and after static stretching for 30 ($n = 20$) and 60 seconds ($n = 20$). (*) Significant difference from pre- to post-stretching ($p < 0.05$)

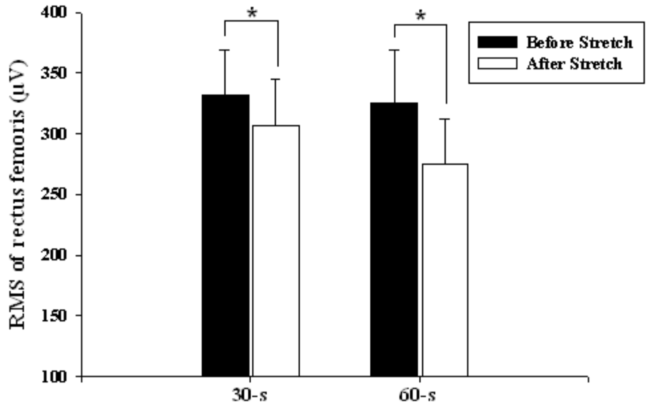

Figure 4. EMG activity of the *rectus femoris* before and after static stretching for 30 ($n = 20$) and 60 seconds ($n = 20$). (*) Significant difference from pre- to post-stretching ($p < 0.05$)

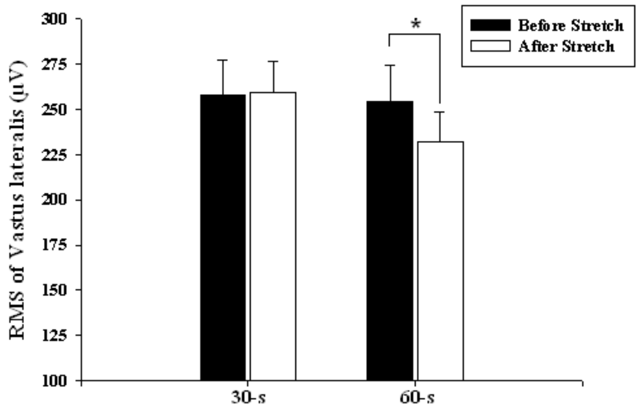

Figure 5. EMG activity of *vastus lateralis* before and after static stretching for 30 ($n = 20$) and 60 seconds ($n = 20$). (*) Significant difference from post-stretching for 60 seconds to pre-stretching for 60 seconds, and to pre- and post-stretching for 30 seconds ($p < 0.05$)

relative force or peak force between the two stretching durations used ($p > 0.05$). In addition, the EMG values for RF decreased significantly in both stretching durations ($p > 0.05$). However, the multifactorial ANOVA revealed a significant difference in time intervention and muscles, where a significant decrease in EMG activity was only observed in the VL when stretched for 60 seconds, but not for the 30-second protocol.

Discussion

The results of the current study demonstrate decreases in muscle performance after both stretching procedures. This reduction in muscle performance is in agreement with the findings of other authors who used several stretching protocols [2, 3, 5–7, 12–15, 18, 24, 25].

Different stretching repetition durations have been found in the literature, ranging from 10 seconds [7],

Table 1. Mean ± Standard Deviation (confidence interval at 95%) of normalized force and EMG activity before and after stretching for 30 and 60 seconds

	30 seconds	60 seconds
Changes in normalized force[1]		
Force	0.94 ± 0.05 (0.91 – 0.95)	0.91 ± 0.06 (0.89 – 0.92)
Peak force	0.96 ± 0.05 (0.94 – 0.97)	0.92 ± 0.07 (0.88 – 0.94)
Changes in normalized EMG[2]		
RF	0.94 ± 0.16 (0.86 – 1.0)	0.87 ± 0.16 (0.80 – 0.91)
VL	1.02 ± 0.13* (0.96 – 1.06)	0.93 ± 0.13 (0.86 – 0.96)

[1] Normalized data were used for analysis of the force variation. Percentages of variation between force before and after stretching were used
[2] Normalized data were used for analysis of the EMG activity variation. Percentages of variation between EMG activity before and after stretching were used
* Significant difference from 30 to 60 seconds ($p < 0.05$)

15 seconds [8, 19, 25], 30 seconds [4–7, 9, 13, 19], 45 seconds [3, 16], 60 seconds [7, 18], up to 120 seconds [15]. In the current study, significant reductions in mean and peak muscle strengths were found with both stretching repetition protocols (30 and 60 seconds), demonstrating that the stretch duration did not influence the decreases in strength. These results do not corroborate the findings of Ogura et al. [18], who compared stretching durations of 30 and 60 seconds in college football players. These authors reported that only the 60-second stretching protocol caused a reduction in isometric force of the knee flexor muscles, despite a significant increase in muscle flexibility with both stretching durations. Nevertheless, another study which used the same amount of stretching repetitions as the present study, revealed significant decreases in eccentric, concentric, and isometric forces with 15 and 30 seconds of stretching, however, there were no significant differences between the two duration lengths of stretching repetitions [19]. Similarly, when comparing four different stretching durations of 10, 20, 30, and 60 seconds, Siatras et al. [7] reported an isometric peak torque reduction with only 30 (8.5%) and 60 seconds (16%), assuring the duration of static stretching influenced the muscle peak torque. Finally, Unick et al. [8] found no changes in vertical jump performance using stretching duration of 15 seconds in trained women.

It is postulated that mechanical factors are responsible for the reduction of force by altering the viscoelastic properties of the muscle and muscle stiffness [2, 6, 14, 15]. The connective tissue, through musculotendineous stiffness, is important for strength transmission to bone [24]. Thus, a more compliant musculotendinous unit can cause an alteration on reaction time and muscle activation [16]. Fowles et al. [14] stated after the release of the fascia through surgical procedure, there is a loss of 15% of muscle strength in dogs, followed by a decrease of 50% in intracompartimental pressure during the contraction. Other mechanical factors such as increasing sarcomere length, hence increasing the sarcomere, shortening distance and changing the muscle length–tension relationship, may decrease the muscle contractile capacity to produce force [2]. As a result, stretching may induce changes in the length–tension relationship, adversely affecting muscle performance [2, 4, 5, 15, 16].

Zakas et al. [25] studied the effect of different amounts of stretching on muscle strength at various isokinetic velocities in young male soccer players using two static stretching protocols of the quadriceps, 3 repetitions of 15 seconds and 20 repetitions of 15 seconds. Significant reductions in force at all angular velocities were found only with the protocol of 20 repetitions, thus, demonstrating that stretching may have a cumulative effect on the muscle and/or connective tissue, particularly when using a large number of repetitions. According to the authors [26], one of the primary factors leading to a decrease in muscle strength is the occurrence of micro injuries in the muscle during the stretch, mainly by increasing the creatine kinase enzyme found in the blood of subjects who had performed the stretching. Their results revealed that stretching can generate an intense mechanical effect on the muscle fibers and that this effect may be another possible causal factor in post stretching muscle strength reduction.

It has been found that the effect of stretching on muscle strength may be temporary [14]. Fowles et al. [14] measured muscle strength before, immediately after, and at certain intervals up to 60 minutes after stretching. Their results demonstrated that force was reduced by 28% immediately after stretching, 21% in the 5th minute, 13% in the 15th minute, 12% in the 30th

minute, 10% in the 45th minute, and 9% after the 60th minute. These data revealed that stretching induced temporary changes in muscle strength, with the greatest decrease in strength observed immediately after stretching. Thus, it is understood that not only mechanical factors but also neural factors may have an influence on the strength reduction [2, 5, 14, 15].

Regarding our EMG findings, many studies report a reduction of EMG activity after stretching, which corroborates the findings of this study [2, 5, 14, 15]. Conversely, others have found no decreases in EMG activity following stretching [13, 20]. Nonetheless, we are unaware of any studies that have analyzed the influence of stretching duration on EMG activity of the quadriceps muscle.

The current results demonstrate that the normalized EMG (RMS) of the RF decreased in both durations of stretching, whereas the VL EMG activity decreased only in the 60-second repetition duration protocol. Hence, a longer period (180 seconds) was necessary for a significant reduction in the EMG activity of the VL muscle, which appears to have a time-dependent behavior. We hypothesized that this can be explained by the anatomical position of the VL, a monoarticular muscle which stretches only when the knee is flexed. Instead, the RF is a biarticular muscle stretching over two joints during both hip extension and knee flexion. Thus, the RF muscle can be lengthened to a greater degree during stretching allowing for more stretching-induced inhibition independently of intervention time.

Avela et al. [2] studied the neural responses of soleus and gastrocnemius muscles after 1 hour of rapid and repeated stretching. These authors reported a reduction in force and EMG activity of the soleus and medial gastrocnemius muscles due to a change in the behavior of the tendon-aponeurosis system, particularly a plastic deformation, which combined affected the proprioceptive "feedback" leading to a decrease in muscle recruitment. However, the current study used more practical stretching durations and a number of repetitions similar to interventions used by coaches and athletes, allowing the results to be more applicable to sports settings.

The reduction of EMG activity found in the study can be explained by a change in neural factors that led to changes in neuromuscular recruitment strategies [2, 14, 15]. These peripheral neural factors include: changes in muscle fiber firing rates [6], activation of the autogenic inhibition reflex involving the Golgi tendon organs stimulated during the stretch [2, 14, 15], activation of joint mechanoreceptors (type III afferent) and pain receptors (type IV afferent) stimulated during the stretching providing a reduction of nerve impulses to the stretched muscle [5, 14], and muscle inhibition by joint compression caused by stretching due to excessive joint range of motion [4]. In the present study, both stretching times of 30 and 60 seconds were enough to stimulate the aforementioned afferent pathways and consequently reduce RF muscle performance.

The results of the current study indicate an acute influence of stretching on muscle activation, suggesting that changes in proprioceptive "feedback" can lead to failure in the strategies of muscle recruitment, hence reducing its activation [14]. In the classic study of Fowles et al. [14], it is reported that 60% of the stretching-induced reduction of force up to 15 minutes is due to neural factors. Thus, neural factors affect the strength initially and mechanical factors may last for a longer period, affecting the strength for up to one hour.

Since most exercise and sports activities are dynamic, the isometric muscle strength assessment may be seen as one possible limitation of the present study. Nevertheless, this procedure was used based on the belief that isometric muscle actions increase the reliability for EMG data collection as proposed by De Luca [26]. In this study, the contralateral leg was not used as a control because decreases of muscle strength in the unstretched contralateral limb have been reported [2, 5]. The main cause for this phenomenon could be a deficit originated from central nervous system, through fatigue in the supraspinal centers [2, 5]. Therefore, it was decided to measure only the dominant leg.

The results of current study suggest that an acute bout of static stretching can lead to a significant decrease in muscle strength and EMG activity in young men. In addition, stretching duration does not appear to have a direct influence on reductions in strength and EMG activity, thus demonstrating that other factors may be involved. It is recommended that more studies should be developed to analyze variables not yet studied, such as the influence of different types, durations, and intensities of stretching on strength and EMG activity and in other population aimed at promoting the scientific knowledge pertaining to the influence of stretching on muscle performance.

Limitation of our study was that only one muscle group underwent the static stretching trial, which is a rare situation in the practical athletic field. In addition, it is important to note that the isometric contraction duration was short (10 seconds) so as not to induce muscle fatigue, because otherwise there would be expected an increase of EMG amplitude associated to muscle fatigue, which was not observed, but we think other studies should consider the possibility of fatigue development when using maximal isometric contractions and they might adopt shorter contraction duration than 10 seconds.

Conclusions

Several studies have reported that acute static muscle stretching may temporarily reduce muscle activation and impair a muscle's capacity to produce force, thus affecting athletes' performance in sports and exercises requiring maximal muscular strength and power development. Our results confirm this hypothesis and reveal that stretching for repetitions of 30 seconds is sufficient to cause a reduction in muscle force. For this reason, coaches and athletes should avoid flexibility training which consists in stretching repetitions of 30 seconds or more prior to competitions. Other suggestion is that more reasonable stretching protocols or post-exercise stretching may provide a useful alternative while attempting to avoid stretching-induced performance decrements.

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