

## Effect of stretching on agonist–antagonist muscle activity and muscle force output during single and multiple joint isometric contractions

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**Eight moderately active male subjects were tested for peak force in an isometric knee extension test and peak force and rate of force development in an isometric squat test. Both tests were performed at a 100° knee angle and average integrated electromyography (IEMG) was measured from the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) muscles. Subjects performed the two conditions, stretching (S) or control (C) in a randomized order. Subjects were tested for baseline strength measures in both the isometric knee extension and isometric squat and then either stretched or sat quietly for 10 min. Following S or C subjects were then tested at six time points. Following S peak force in the isometric knee extension was significantly ( $P \leq 0.05$ ) less than C at 1, 2, 8 and 16 min post. No**

**significant difference in peak force was found between S and C in the isometric squat. However, following S the rate of force development in the isometric squat was significantly less than C at immediately post. No significant differences were observed in IEMG of the VM or VL between S and C in either the isometric knee extension or isometric squat. However, IEMG significantly decreased in the BF at 1 min post after S in comparison with C in both the isometric knee extension and isometric squat. Stretching appears to decrease muscle force output in a single joint isometric contraction and rate of force development in a multiple joint isometric contraction. Possible changes in agonist–antagonist muscle activity patterns need to be further examined.**

Static stretching of a single muscle group has been shown to decrease the force output of that muscle around a single joint in both dynamic and isometric contractions (Behm et al., 2001; Nelson et al., 2001; Evetovich et al., 2003). Fowles et al. (2000) reported that 30 min of time under stretch of the plantarflexors resulted in decreased isometric force output of the muscle for up to 60 min. Power et al. (2004) also reported a force deficit of the quadriceps muscles for up to 120 min after 4.5 min of time under stretch. No known investigations have reported the effect of stretching on multiple joint dynamic or isometric maximal force output. However, the influence of stretching on multiple joint dynamic power activities has resulted in different results (Young & Elliot, 2001; Koch et al., 2003; Young & Behm, 2003). Koch et al. (2003) has shown that stretching had no positive or negative influence on standing broad jump performance. In contrast, Young and Behm (2003) reported a negative influence of static stretching on drop jump and counter-movement jump performance.

Several mechanisms have been proposed for the observed decrease in muscle force output around a single joint with stretching. These include a decrease in muscle stiffness (Kubo et al., 2001; Evetovich et al.,

2003), muscle inactivation during artificial muscle stimulation (Behm et al., 2001) and decreased muscle activity during a maximal voluntary contraction (Fowles et al., 2000). Kubo et al. (2001) reported that the stiffness of tendon structures of the triceps surae complex was significantly reduced after stretching. In addition, Evetovich et al. (2003), through the use of mechanomyography reported that muscle stiffness was reduced after stretching. Studies examining the structural proteins within muscle (such as titin) indicate that stretching can in fact reduce muscle stiffness and may subsequently have a negative effect on that muscle's ability to generate force (Cazorla et al., 1999). These reported mechanisms have been theorized to reduce muscle force output because of changes in motorneuron excitability states (observed as changes in muscle activity) and by disrupting the force transmission system via structural muscle protein damage (i.e. disruption to muscle stiffness).

Fowles et al. (2000) reported a decrease in muscle activity after stretching and it has been proposed that stretching decreases motor neuron excitation states (Avela et al., 1999). This has been substantiated by an observed decrease in H-reflex measurements after stretching (Avela et al., 1999; Guissard et al., 2001;

Guissard & Duchateau, 2004). It has been suggested that inhibitory mechanisms after stretching are both pre- and post-synaptic (Guissard et al., 2001). Regardless of the mechanism it would seem plausible that changes in muscle force output as a result of stretching would influence both single and multiple joint dynamic or isometric activities simultaneously. However, the determination of changes in explosive muscle force output in single joint tests (Behm et al., 2001; Nelson et al., 2001; Evetovich et al., 2003) has been much more consistent than in multiple joint tests (Young & Elliot, 2001; Koch et al., 2003; Young & Behm, 2003).

Muscle activity pattern strategies used in multiple joint activities (i.e. squat) may override changes in external force output because of changes in the force producing capacity of the stretched musculature (agonist muscles-quadriiceps). Meaning, the antagonist muscles, such as the hamstrings, or other synergist muscles (triceps surae) may be compensating for the lower force producing capacity of the stretched musculature (agonist muscles). Therefore, the overall force output of the multiple joint movement is not decreased after stretching only the agonist muscle (quadriiceps). It has been reported that agonist-antagonist muscles in the squat share a common motorneuron pool (Mullany et al., 2002) acting in unison during lower body force exertions (Pincivero et al., 2000). However, it has been suggested that reciprocal inhibition of antagonist muscles is based on the amount of agonist muscle activity observed (Crone, 1993). Therefore, any changes in agonist activity may have a magnified effect on decreasing antagonist muscle activity through a reflex loop (Crone, 1993). Antagonist muscle activity may be of no consequence in single joint force output capabilities. However, in multiple joint activities, such as a squat, agonist and antagonist muscle could both contribute to force output. For e.g. because of the two joint actions of the quadriiceps and hamstring muscle groups around the knee and the hip. Therefore, the overall force output in a multiple joint movement may be affected after stretching even if only the agonist muscle is stretched.

The purpose of this investigation was to determine if stretching would influence both single and multiple joint isometric force output. Furthermore, changes in the relationship between the amount of activity of agonist-antagonist muscles was measured to determine if this had some influence in observed changes in force production after stretching only the agonist muscles.

## Methods

### Subjects

Eight moderately active college aged males (age:  $21.4 \pm 0.7$  years; height:  $178.1 \pm 9.0$  cm; weight:  $82.2 \pm 10.8$  kg) partici-

pated in this study. None of the subjects were involved in regimented exercise program or involved in any type of sport competition. Approval by the Institutional Review Board for the Protection of Human Subjects of Appalachian State University was obtained before the investigation. All subjects were informed of any risks associated with participation in the study and signed an informed consent form prior to participating in any of the testing and/or training.

### Study design

Subjects participated in one testing session. The session began by obtaining height and weight. Electrodes were then placed on the vastus medialis (VM), vastus lateralis (VL) and biceps femoris (BF) of the thigh musculature. Subjects then rode a stationary bicycle for 5 min at a standardized resistance at 80 revolutions/min. Baseline force output testing was then completed in both the isometric knee extension and isometric squat. The subject was then randomly exposed to either the control (C) condition or stretching (S) condition. Post measurements were then taken at the following intervals: immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). The two conditions were separated by 30 min of rest or after the maximum force level in the both the isometric knee extension and isometric squat was returned to the initial baseline force value for that session.

### Treatments

The C condition consisted of 10 min of quiet sitting. The S condition consisted of three sets of 33 s stretches of the quadriiceps muscle complex (total stretch time of 270 s). Each repetition was separated by 30 s of rest and each set was separated by 2 min of rest. Subjects were asked to lie prone on an examination table and then both knees were flexed into a stretching position. Maximal effort by the researcher was placed on the flexed leg for the duration of each 30 s stretch.

### Isometric knee extension and isometric squat

The isometric knee extension was performed by having the subject sit in chair with both legs fixated at a  $100^\circ$  knee angle. On the dominant leg of the subject a force transducer (SL1000lb, Lafayette Instrument Company, Lafayette, Indiana, USA) was used to record the peak force output (Jackson Evaluation System, Lafayette Instrument Company) during each 3 s isometric contraction performed. The non-dominant leg exerted force simultaneously against an immovable strap. The isometric squat was performed by having the subject stand on a force platform (BP6001200, AMTI, Watertown, Massachusetts, USA) under a fixed bar position at a  $100^\circ$  knee angle (Stone et al., 2003) and perform a maximal isometric contraction again for 3 s. The force-time curve was recorded using a shielded BNC adapter chassis (BNC-2090, National Instruments, Austin, Texas, USA) and an A/D card (NI PCI-6014, National Instruments). LabVIEW (National Instruments, Version 7.1, Texas, Austin, USA) was used for recording and analyzing the data. Peak force during the first 200 ms (PF200), first 400 ms (PF400), first 600 ms (PF600), first 800 ms (PF800), first 1000 ms (PF1), first 2000 ms (PF2) and peak force of the whole 3 s contraction (PF3) and average rate of force development for the first 400 ms of the force-time curve were calculated.

For baseline testing in the isometric knee extension one warm-up trial was performed by asking the subject to exert

approximately 50% of their maximal force level for 3 s. Subjects were then asked to exert a maximal force for two trials with 2 min of rest in between. If the force output from the second trial was no more than 5% higher than the first trial then the test was considered complete. If not, a third trial was performed and compared to the second trial. If the third trial was no more than 5% higher than the second trial then the test was considered complete. All subjects reached a maximal force level within these three trials for all conditions. The maximal force value from the best trial was used for comparison. This process was repeated for the isometric squat.

**Electromyography (EMG)**

EMG was collected at 1000 Hz using a telemetry transmitter (eight channel, 12 bit analog to digital converter, NORAXON USA, Scottsdale, Arizona, USA) during the isometric knee extension and the isometric squat. A disposable surface electrode (NORAXON USA, 2 cm inter-electrode distance, 1 cm circular conductive area) was attached over the belly of the VM, VL and BF muscle of the subjects dominant leg distal to the motor point. All electrodes were appropriately applied to the target muscles and aligned parallel to the muscle fibers. Appropriateness of skin preparation was insured by a measured impedance of less than 5 kΩ. The myoelectric signal was detected by the receiver-amplifier (Telemetry 900, gain = 2000, differential input impedance = 10 MΩ, bandwidth frequency 10–500 Hz, common mode rejection ratio = 85 dB, NORAXON USA) and then sent to an A/D card (KEITHLEY, KPCMCIA-12AI-C, Cleveland, Ohio, USA) and analysed using MyoResearch software (Version 4.0, NORAXON USA). The signal was full wave rectified and filtered (six pole butterworth, notch filter 60 Hz, band pass filter 10–200 Hz). The integrated value (mVs) was calculated and then averaged over the three second isometric contraction (mV) (IEMG).

**Statistical analysis**

A general linear model (GLM) repeated measures analysis with a Bonferroni post-hoc test was used to determine between- and within-group differences. The criterion  $\alpha$  level was set at  $P \leq 0.05$ . All statistical analyses were performed through the use of a statistical software package (SPSS, Version 11.0, SPSS Inc., Chicago, Illinois, USA).

**Results**

**Isometric knee extensor and isometric squat**

Peak force in the isometric knee extension decreased significantly after S and was significantly lower than the peak force in comparison with C at 1m-post, 2m-post, 8m-post and 16m-post (Fig. 1, Table 1). Peak force in the isometric squat after S decreased significantly at imm-post and 4m-post but was not significantly different from C (Fig. 2). There was a significant time  $\times$  condition interaction effect between the percentage decrease in force between the isometric knee extension and isometric squat at  $P = 0.034$ . Meaning, the decrease in force output attributable to stretch was significantly different between the isometric knee extension and isometric squat. Rate of force development decreased signifi-

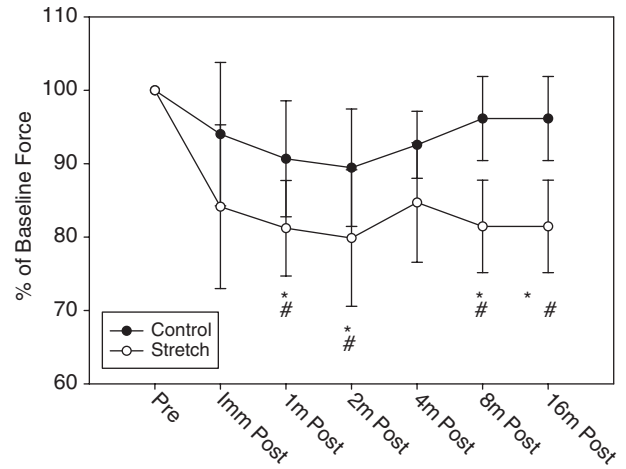


Fig. 1. Peak force during a 3 s knee extension isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from C value.  $P \leq 0.05$ .

cantly at imm-post after S and was significantly different from C (Fig. 3). S did not result in any statistically significant decreases in PF200, PF400, PF600, PF800, PF1 or PF2. However, a trend toward lower values was observed after S (imm-post) in comparison to C (Fig. 4).

**EMG**

During the isometric knee extension average IEMG of the VM and VL did not change significantly after S and was not significantly different from C (Figs 5 and 6, Table 1). However, IEMG of BF decreased significantly at imm-post after S and was significantly different from C (Fig. 7). During the isometric squat IEMG of the VM and VL did not change significantly after S and was not significantly different from C (Figs 8 and 9). However, IEMG of BF decreased significantly at imm-post, 1m-post and 2m-post and was significantly different from C (Fig. 10).

**Discussion**

The primary finding in this investigation is that stretching reduces peak force in single joint isometric contractions (isometric knee extension) and rate of force development in a multiple joint isometric contraction (isometric squat). This was coincidental with a decrease in the muscle activity of the antagonist muscle (biceps femoris), which was not stretched. No changes in the muscle activity of the VM or VL, which were stretched, were observed. Because of the

Table 1. Values (means ± SD) reported for all dependent variables

	Baseline	imm-post	1m-post	2m-post	4m-post	8m-post	16m-post
<i>Control variable</i>							
IKPF (N)	683 ± 118	645 ± 140	621 ± 122	610 ± 117	630 ± 100	657 ± 119	653 ± 115
ISPF (N)	2466 ± 465	2352 ± 444	2322 ± 413	2329 ± 460	2320 ± 490	2382 ± 468	2316 ± 542
ISRFD (N/s)	4661 ± 1758	3988 ± 1364	4191 ± 2012	3290 ± 1309	4187 ± 1768	4046 ± 2817	3634 ± 1774
IKVM (mV)	1.98 ± 0.67	1.77 ± 0.58	1.87 ± 0.47	1.70 ± 0.34	1.78 ± 0.38	1.85 ± 0.44	1.75 ± 0.34
IKVL (mV)	2.20 ± 1.07	1.88 ± 0.63	1.91 ± 1.01	1.90 ± 0.68	1.85 ± 0.72	1.84 ± 0.76	1.99 ± 0.89
IKBF (mV)	0.18 ± 0.11	0.17 ± 0.09	0.15 ± 0.08	0.13 ± 0.06	0.14 ± 0.06	0.12 ± 0.05	0.12 ± 0.05
ISVM (mV)	2.00 ± 0.48	1.93 ± 0.44	1.92 ± 0.45	1.93 ± 0.38	1.97 ± 0.44	1.97 ± 0.39	1.75 ± 0.41
ISVL (mV)	1.69 ± 0.53	1.74 ± 0.70	1.61 ± 0.46	1.66 ± 0.53	1.62 ± 0.53	1.64 ± 0.61	1.68 ± 0.63
ISBF (mV)	0.26 ± 0.12	0.27 ± 0.14	0.26 ± 0.12	0.28 ± 0.09	0.25 ± 0.09	0.24 ± 0.14	0.24 ± 0.12
<i>Stretch variable</i>							
IKPF (N)	709 ± 160	598 ± 163	572 ± 120 <sup>*,†</sup>	574 ± 172 <sup>*,†</sup>	603 ± 158	576 ± 132 <sup>*,†</sup>	649 ± 150 <sup>*,†</sup>
ISPF (N)	2448 ± 583	2251 ± 389 <sup>*</sup>	2257 ± 424	2284 ± 406	2278 ± 443 <sup>*</sup>	2311 ± 492	2284 ± 420
ISRFD (N/s)	4954 ± 1822	3052 ± 1612 <sup>*,†</sup>	4151 ± 1504	3569 ± 1951	3721 ± 1867	3870 ± 1464	3532 ± 975
IKVM (mV)	1.98 ± 0.60	2.05 ± 0.89	1.79 ± 0.46	1.88 ± 0.77	1.96 ± 0.39	2.00 ± 0.42	2.05 ± 0.58
IKVL (mV)	2.08 ± 0.71	1.93 ± 0.90	1.53 ± 0.41	1.66 ± 0.55	1.65 ± 0.41	1.66 ± 0.53	1.87 ± 0.63
IKBF (mV)	0.17 ± 0.08	0.16 ± 0.10	0.11 ± 0.09 <sup>*,†</sup>	0.14 ± 0.10	0.18 ± 0.11	0.15 ± 0.08	0.18 ± 0.08
ISVM (mV)	1.93 ± 0.36	1.89 ± 0.39	2.01 ± .053	1.95 ± 0.37	1.94 ± 0.41	2.07 ± 0.46	1.97 ± 0.47
ISVL (mV)	1.63 ± 0.47	1.51 ± 0.35	1.59 ± 0.40	1.53 ± 0.26	1.55 ± 0.36	1.57 ± 0.45	1.50 ± 0.41
ISBF (mV)	0.28 ± 0.10	0.17 ± 0.11 <sup>*,†</sup>	0.18 ± 0.12 <sup>*,†</sup>	0.21 ± 0.13 <sup>*,†</sup>	0.26 ± 0.14	0.30 ± 0.14	0.25 ± 0.13

\*Significant difference from corresponding baseline value ( $P \leq 0.05$ ).

†Significant difference from corresponding control value ( $P \leq 0.05$ ).

imm-post, immediately post; 1m-post, 1 min post; 2m-post, 2 min post; 4m-post, 4 min post; 8m-post, 8 min post; 16m-post, 16 min post.

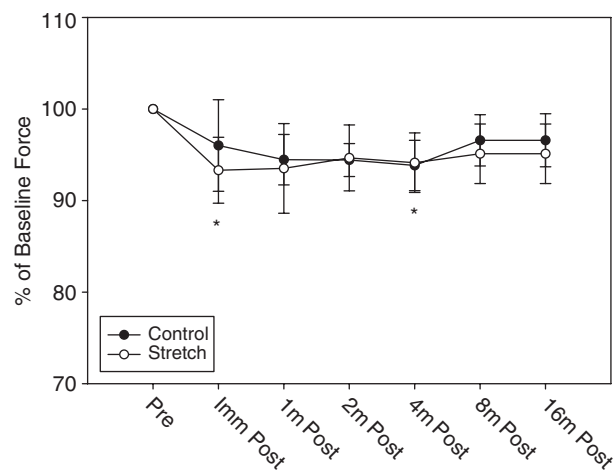


Fig. 2. Peak force during a 3 s squat isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from C value.  $P \leq 0.05$ .

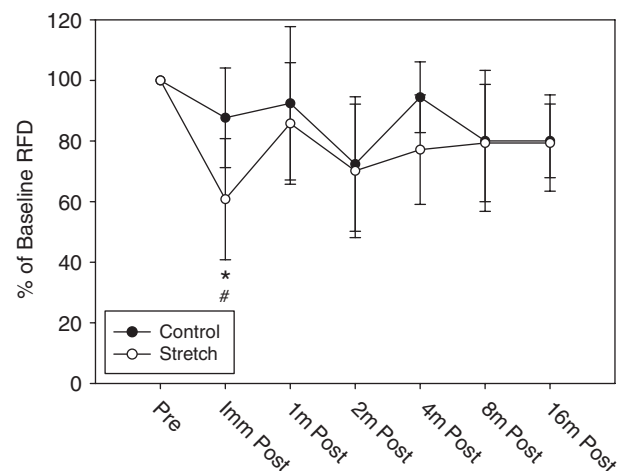


Fig. 3. Rate of force development during the first 400 ms during a 3 s squat isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from C value.  $P \leq 0.05$ .

two joint action of the both the quadriceps and hamstring muscle groups in the squat stretching may have caused a shift in the synergistic relationship between the agonist-antagonist muscle activity resulting in a decrease in external force output measured.

The decrement in force output in the single joint isometric contraction after stretching observed in this

investigation is consistent with several other investigations (Behm et al., 2001; Nelson et al., 2001). However, the length of time that the stretch induced force decrement lasted in this investigation was much shorter than previously reported (Fowles et al., 2000; Power et al., 2004). Within 30 min of completion of either the control or treatment condition the maximum force level in both the isometric knee extension

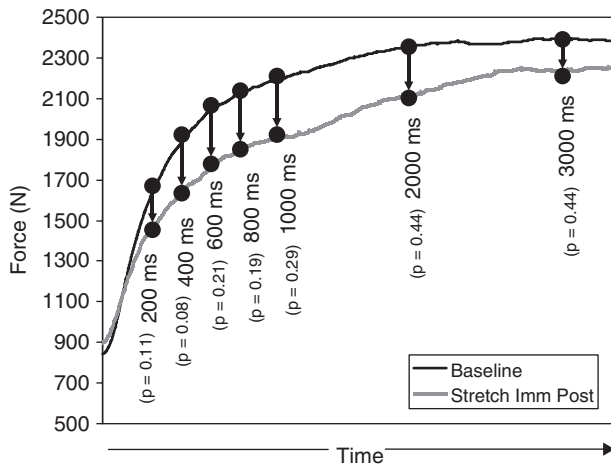


Fig. 4. Average force–time curves between baseline and immediately post (imm-post) measurements after stretching (S). *P*-values are reported for comparison of force values at 200 ms (PF200), 400 ms (PF400), 600 ms (PF600), 800 ms (PF800), 1000 ms (PF1), 2000 ms (PF2) and 3000 ms (PF3).

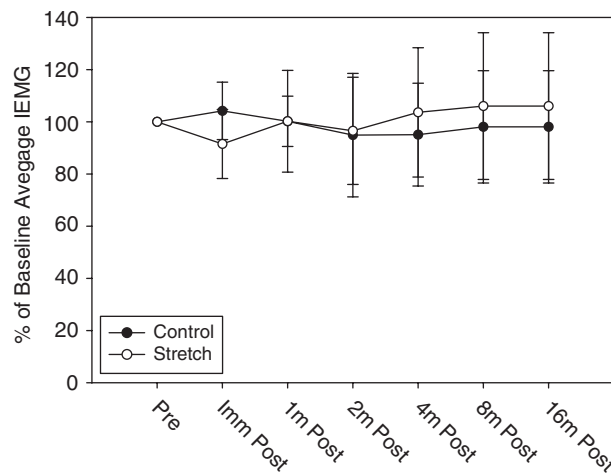


Fig. 5. Average integrated electromyography (IEMG) of the vastus medialis (VM) during the 3 s knee extension isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from control (C) value.  $P \leq 0.05$ .

and isometric squat was returned to the baseline value in the current study. No clear explanation of this contradiction can be provided. Time under stretch in this investigation was 4.5 min which is the same as the time under stretch reported by Power et al. (2004).

Acute changes in force output after stretching have been attributed several different mechanisms. One suggested mechanism has been changes in muscle stiffness and decreased muscle activity (Fowles et al., 2000; Kubo et al., 2001; Evetovich et al., 2003). The

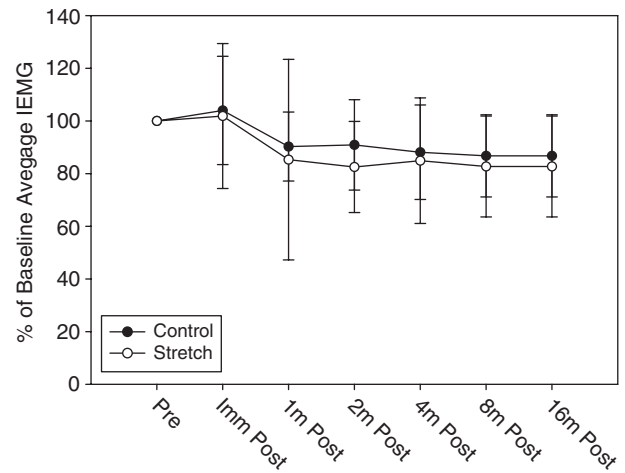


Fig. 6. Average integrated electromyography (IEMG) of the vastus lateralis (VL) during the three second knee extension isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from control (C) value.  $P \leq 0.05$ .

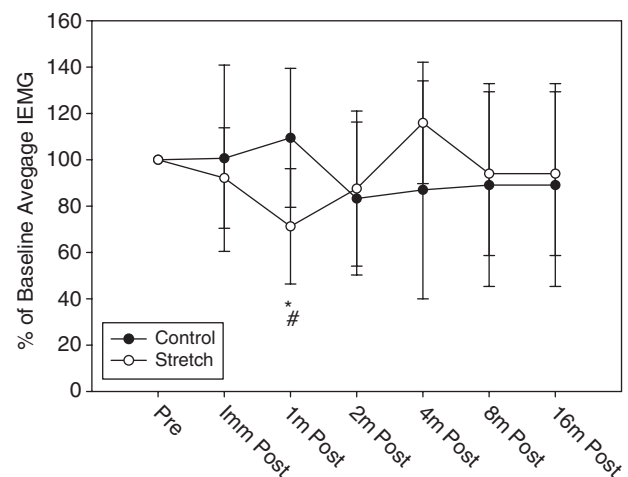


Fig. 7. Average integrated electromyography (IEMG) of the biceps femoris (BF) during the three second knee extension isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from C value.  $P \leq 0.05$ .

muscle activity of the agonist muscle in this investigation did not change significantly. However, antagonist muscle activity did decrease significantly immediately after stretching. It is unclear as to why this occurred as this muscle was not directly stretched. Several afferent feedback mechanisms influence the balance of muscle activity between ago-

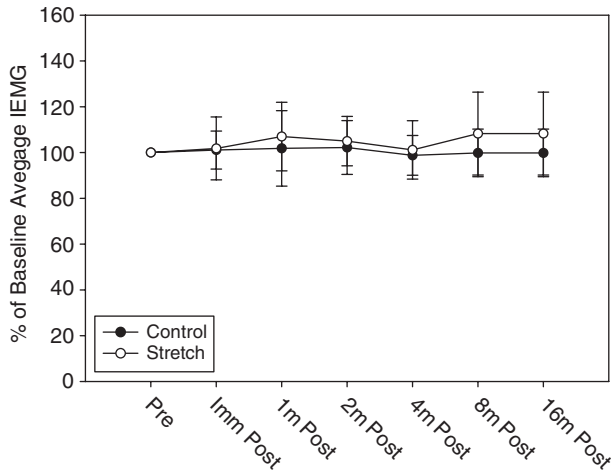


Fig. 8. Average integrated electromyography (IEMG) of the vastus medialis (VM) during the 3 s squat isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from control (C) value.  $P \leq 0.05$ .

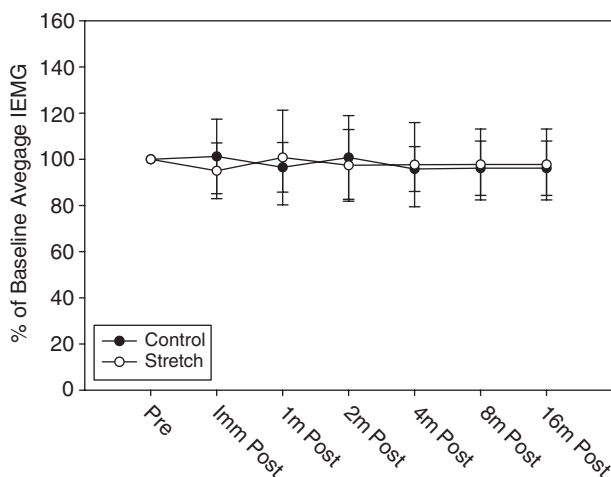


Fig. 9. Average integrated electromyography (IEMG) of the vastus lateralis (VL) during the 3 s squat isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from C value.  $P \leq 0.05$ .

nist-antagonist muscles and may have been altered as a result of stretching the agonist muscle (Crone, 1993).

Rate of force development during an isometric contraction is often used as an indication of muscle power capabilities (Stone et al., 2003). It has been correlated to several variables related to athletic

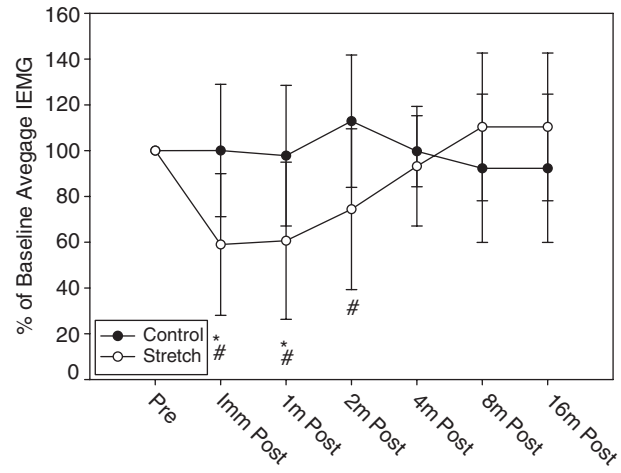


Fig. 10. Average integrated electromyography (IEMG) of the biceps femoris (BF) during the 3 sec squat isometric contraction after the control (C) and stretching (S) conditions. Time points are immediately post (imm-post), 1 min post (1m-post), 2 min post (2m-post), 4 min post (4m-post), 8 min post (8m-post) and 16 min post (16m-post). Values are presented as a percentage of baseline peak force. \*Significant decrease in peak force from baseline force level. #Significantly different from C value.  $P \leq 0.05$ .

performance such as vertical jump height (Bruhn et al., 2004). As previously mentioned some studies have shown that stretching has a negative influence on muscle power (Koch et al., 2003). However, it is unusual that in this investigation stretching did not significantly decrease peak force in the isometric squat but did result in a significant decrease in rate of force development immediately post. However, there was a trend in reduced muscle force output (PF200, PF400, PF600, PF800, PF1, PF2) after stretching in the isometric squat that could have ultimately reduced the rate at which force could be produced with respect to time (rate of force development). The important relationship between rate of force development and maximal force production has been outlined by Aagaard et al. (2002). The decrease in rate of force development in the isometric squat after S was coincidental with a decrease in muscle activity of the antagonist muscle but not the agonist muscle. As mentioned above the afferent feedback loops that influence co-activation of agonist-antagonist may have been influenced by the stretching of the agonist and subsequently resulted in a decreased rate of force development (Crone, 1993). This may be because of the two joint activity of the hamstring muscle group in terms of its action around the hip.

It is not clear at this time why the attenuation in force output was much clearly observed in the isometric knee extension in comparison with the isometric squat. The peak force during the isometric knee extension was reduced consistently by almost

20%. In contrast the reduction in force during the isometric squat was approximately 7%. The isometric squat involved many more muscle groups in comparison with IK. Thus, other muscles not stretched could have possibly compensated for the decrease in force output by the stretched muscles. Therefore, the potential negative influence of stretching on multi-joint dynamic activities is still a question to be remained answered. This is a possible reason for some of the conflicting results observed in previous investigations in this area with multi-joint tasks (Young & Elliot, 2001; Koch et al., 2003; Young & Behm, 2003).

In conclusion, clearly stretching can cause a decrease in muscle force capabilities up to 16 min after stretching and thus would not be recommended for use a general warm-up procedure, especially prior to strength/power activities. Currently, general recommendations for warm-up include stretching and should be carefully considered when maximizing athletic performance is of importance. It is not clear how applicable these results would be to dynamic activities, further investigation in this area should be performed.

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## Perspectives

Based on the observations from the current investigation care should be taken when implementing warm-up procedures, such as stretching, prior to activities requiring maximal force production or high rates of force development. This is supported by previous investigations as well (Behm et al., 2001; Nelson et al., 2001). Alternatives to stretching maybe post-activation potentiation activities (Young & Behm, 2003). However, there is no clear indication of the dose–response relationship between stretching and its attenuating effect on muscle force. Further investigation is necessary to establish clear criteria for application of various stretching protocols relative to athletic performance. Future investigations should continue to examine the dose–response of stretching to changes in rate of force development and peak force in both single and multiple joint tasks. In addition, determination of the exact mechanism for observed changes in these variables should be examined as well.

**Key words:** electromyography, strength, power.