Acute Muscle Stretching Inhibits Maximal Strength Performance

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It is widely conjectured that increasing flexibility (increased joint range of motion) will promote better performances and reduce the incidence of injury (for review see Shellock & Prentice, 1985; Smith, 1994). Consequently, stretching exercises designed to enhance flexibility are regularly included in both the training programs and the pre-event warm-up activities of most athletes. Notwithstanding the widespread use of stretching, research documenting the performance benefits of stretching is limited. The majority of the studies have either investigated methods to improve flexibility (for review see DeVries & Housh, 1994), or have been concerned with the relationship between injury occurrence and inherent flexibility (for review see Safran, Scaber, & Garret, 1989; Shellock & Prentice, 1985; Smith, 1994), with little attention paid to whether stretching actually influences performance. Furthermore, those studies that have attempted to establish the influence of stretching on performance have mainly investigated the effects of long-term or chronic stretching programs rather than the benefit of acute stretching done just prior to the event. For example, Dintiman (1964) found that sprint performance was improved when a stretching regimen was included with regular sprint training. Also, Worrell, Smith, and Winegardner (1994) found that 3 weeks of hamstring stretching increased both eccentric and concentric isokinetic knee-flexion torque production at selected speeds. Additionally, Kokkonen and Lauritzen (1995) reported a significant increase in isotonic hamstring strength at the end of a 12-week stretching program.

Sound experimental evidence, however, to support the notion that performance can be enhanced if stretching exercises are undertaken just prior to an event is lacking. In fact, we have found only one published study that specifically addressed the use of acute stretching on performance. DeVries (1963) reported no change in 100-yard dash times in four individuals when they stretched before a race. Furthermore, we suggest that pre-exercise stretching could even have a negative impact on the performance of skills in which success is related to maximal force output. Wilson, Murphy, and Prvor (1994) have suggested that a still musculotendinous system allows for an improved force production by the contractile component and provided evidence to support this suggestion by demonstrating that concentric performance in the bench press was significantly related to musculotendinous stiffness. Given that the results of several studies (Magnarsson, Simonsen, Aagaard, & Kjar, 1996; Rosebaum & Hennig, 1995; Taylor, Dalton, Scaber, & Garrett, 1990) indicate that the musculotendinous unit becomes less stiff as a result of acute stretching, it is conceivable that stretching could compromise the generation of maximal muscular force. In addition, Thigpen, Moritani, Thiebaud, and Hargis (1985) reported that the Hoffman reflex (H reflex) remained depressed after the triceps surae was released from a sustained stretch. This depressed H reflex suggests that stretching could induce autogenic inhibition of a muscle that could also compromise force production.

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Thus, it would appear that the effect of acute stretching on maximal muscle force production is needed. The purpose of this study, therefore, was to determine the influence of acute-stretching activities on maximal strength performance. Specifically, we investigated whether acutely stretching the hip, thigh, and calf muscles would alter the performance of a one-repetition maximum lift (1RM).

**Method**

**Participants**

Fifteen female and fifteen male college students (Mage = 22 years, SD = 5) enrolled in professional physical education classes, participated in the study. None of the participants engaged in any regular or organized stretching or weight lifting activity. The study was approved by the appropriate institutional review board, and each participant gave both written and oral consent before engaging in the experiment.

**Experimental Protocol**

Each participant performed a 1RM prone-knee flexion and a 1RM seated-knee extension on 2 successive days. On each day, one of two treatments preceded the pair of flexion and extension 1RM lifts. The two treatments were either 10 min of quiet sitting (NS), or 20 min of passive static stretching of the hip, thigh, and calf muscle groups (ST). NS and ST were assigned at random so that half the participants performed NS on the first testing day, and the other half performed ST on the first testing day. To ascertain whether alterations in joint range of motion occurred following either NS or ST, each participant performed a sit-and-reach test on an AcuFlex I sit-and-reach box (Novel Products, Rockton, IL) before and after each treatment. Thus, when the participants entered the laboratory on each testing day, they performed the following activities in order: sit-and-reach Test #1, NS or ST, sit-and-reach Test #2, knee-flexion 1RM, 10–15 min rest, knee-extension 1RM.

**Stretching Protocol**

The ST stretching program consisted of five different static stretching activities designed to stretch all the major muscles involved in knee flexion and extension. The first stretching exercise was a sit-and-reach. The participants sat on the floor with their legs extended and then lowered their heads toward their knees. The second activity was the lotus stretch. Here, the participants sat on the floor in the lotus position and then proceeded to lower their heads to the floor. For the third activity, the heel cord stretch was performed. To do this, each participant first stood with one foot flat on the floor and the other foot placed on a block so that the ball of the foot was 10 cm above the heel. The participants would then lean forward until maximum dorsiflexion was achieved and noticeable tension was felt in the calf. The fourth exercise was a standing half lotus. While standing with one foot flat on the floor, each participant placed the opposite leg in a lotus position on a table. The participant would then alternate lowering the head toward either the foot or the knee of the leg resting on the table. The fifth and final exercise was a quadriceps stretch. The participants stood with their backs to a pommel horse and then placed the superior side of one foot on the pommel horse by flexing at the knee joint. From this position, the participants would lean backward.

Each participant performed all five stretches three times unassisted and three times assisted. The three repetitions for a specific exercise were completed before another exercise was performed. After the five exercises were performed unassisted, the exercises were performed again in the same order but with assistance from an investigator. For each of the unassisted exercises, the participant would assume the appropriate position and lean or lower as far as possible, placing the musculature on stretch. The stretch was then held for 15 s, and the activity was repeated two more times with a 15-s recovery period between the repetitions. The assisted activities were performed in the same manner and for the same length of time as the unassisted; however, for the assisted condition, one of the experimenters would push the participant until he or she verbally acknowledged that the stretch was at the pain threshold. The experimenter would then hold the participant's body at that position for the 15 s. The stretching exercises were usually completed in 20 min. Following the stretching bout, the participant would relax for 10 min before repeating the sit-and-reach test.

**One Repetition Maximum (1RM) Protocol**

Participants performed the knee-flexion 1RM in the prone position using a Nautilus knee-flexion machine (Nautilus, Ocala, FL). Prior to the test, the participants would move the device unweighted until their legs were straight. Lines marking this position were placed on both the stationary and moving parts of the machine, and subsequent lifts were not deemed complete until these marks were in alignment. The initial weight was set at 134 N (30 lb) for women. The weight was then increased to 223 N (50 lb), followed by 267 N (60 lb), and 312 N (70 lb). After a participant lifted 312 N successfully, the weight was increased in 22-N (5 lb) increments until the participant failed to complete a lift. At this point, the load was decreased by 11 N (2.5 lb), and a final attempt
was performed. For the men, the initial weight was 223 N (50 lb). The weight was then increased to 356 N (80 lb), followed by 445 N (100 lb), and 490 N (110 lb). After 490 N, the weight was incremented by 45 N (10 lb) until 623 N (140 lb) was reached. After 623 N, the weight was incremented by 22 N (5 lb) until the participant failed to lift it. The load was then decreased by 11 N (2.5 lb), and participants performed a final attempt. For both the women and men, a 1-min rest was instituted between all lifts.

The knee-extension 1RM test followed a protocol similar to the knee-extension test. The test, however, was performed in a seated position on a Nautilus knee-extension machine. The initial four weights for the female participants were 223 N (50 lb), 356 N (80 lb), 445 N (100 lb), and 490 N (110 lb). After 490 N, the incremental increases were set at 22 N (5 lb). The male participants first lifted, in order, 356 N (80 lb), 534 (120 lb), 668 N (150 lb), and 757 N (170 lb). After 757 N, the weight was incremented by 45 N (10 lb) up to 979 N (220 lb), and then successive increments of 22 N (5 lb) were applied. For all 1 RM tests, the participants were unaware of the progression outlined above, nor were they allowed to visually determine the load for each lift. Knowledge of individual or overall performances was not provided until the end of the study.

**Statistical Analysis**

The 1RM measurements and the sit-and-reach tests were analyzed using paired t tests. The level of significance was set at $p < .05$.

**Results**

Changes in flexibility due to the ST and NS treatments were substantiated through use of the sit-and-reach tests. The ST exercises altered sit-and-reach performance such that the poststretching sit-and-reach scores were significantly, $t(29) = 11.11$, $p < .05$, $\omega^2 = .89$, increased 16% over the initial sit-and-reach scores (see Figure 1). The NS did not have a significant effect upon sit-and-reach performance, $t(29) = .08$, $p > .05$.

The results of the knee-flexion 1RM and the knee-extension 1RM are presented in Figure 2. Following the ST treatment, the average knee-flexion 1RM was significantly less, $t(29) = 5.75$, $p < .05$, $\omega^2 = .52$, than the NS average knee-flexion 1RM (average decline = 7.3%). Likewise, the ST program had a negative influence on knee-extension 1RM, with the 1RM following ST averaging a significant, $t(47) = 8.15$, $p < .05$, $\omega^2 = .68$, 8.1% less than the 1RM following NS.

![Figure 1. The mean (± standard deviation) sit-and-reach scores. The sit-and-reach was measured before (pretest) and after (posttest) the two treatments. An asterisk (*) indicates a posttest sit-and-reach score significantly greater ($p < .05$) than the respective pretest sit-and-reach score.](image)

![Figure 2. The mean (± standard deviation) knee-flexion 1RM and knee-extension 1RM for the nonstretched and stretched groups. An asterisk (*) indicates that the stretched group mean was significantly less ($p < .05$) than the nonstretched group mean.](image)
Discussion

The purpose of the present investigation was to determine the effect of acute muscle stretching on maximal strength performance. The main finding was that a significant decrease in 1RM performance for both knee-flexion and knee-extension occurred following an acute stretching treatment. The data clearly indicate, therefore, that a given regimen of acute stretching can inhibit the maximal strength of the knee flexors and extensors.

The ST treatment might have influenced maximal strength through a reduction in either the passive or active stiffness of the musculotendinous unit. A reduction in passive stiffness and a concomitant increase in the length of the musculotendinous unit following acute static stretching has been demonstrated by Taylor et al. (1990) in in vitro rabbit muscle and by Magnusson et al. (1996) in in vivo human muscle. Although a decrease in the active stiffness of the musculotendinous unit after an acute bout of stretching has not yet been firmly established, Rosenbaum and Hennig (1995) have obtained indirect evidence to suggest such a change takes place. These authors investigated the acute effects of stretching on Achilles tendon reflex activity. Besides finding a decrease in the reflexive peak force and reflexive myoelectrical activity of both the gastrocnemius and soleus muscles, they also found that the passive peak force caused by a tendon tap was significantly reduced following the stretching treatment. The reduction in passive peak force after stretching was interpreted as evidence that the musculotendinous unit had become more compliant. Furthermore, Wilson, Wood, and Elliot (1991) reported an inverse relationship ($r = -0.544; p < .05$) between maximal musculotendinous stiffness and static flexibility. In a subsequent study, Wilson and his group (Wilson, Elliot, & Wood; 1992) also demonstrated that 8 weeks of flexibility training can reduce the stiffness of the musculotendinous unit under maximal load conditions. It is not unreasonable, therefore, to speculate that the knee-extensor and flexor muscles of the participants in the present study became more compliant as a result of the stretching procedure, especially as the participants demonstrated a significant increase in range of motion.

Wilson et al. (1994) provided evidence showing the relationship between muscle stiffness and force production by demonstrating that concentric performance in the bench press is significantly related to active musculotendinous stiffness. These authors suggested that a stiff musculotendinous unit allows the force generated by the contractile component of a muscle to be transmitted to the skeletal system much more effectively than by a compliant unit. In addition, Wilson et al. (1994) suggested that a more compliant system could result in a loss of force production by the contractile component due to altered intramuscular length and velocity conditions. Specifically these researchers surmise that at a given magnitude of contraction a compliant musculotendinous unit would go through a period of rapid and virtually unloaded shortening which would continue until the elastic components were altered sufficiently to transmit the generated force to the bone. Hence, a stiffer musculotendinous unit would produce force at both a longer sarcomere length and a slower shortening velocity, thereby placing the contractile component at a more optimal point, in terms of force production, of both the force velocity and the force-length curves. In the present study, it is possible that the imposed stretching protocol decreased the active stiffness of the knee-extensors and knee-flexors to the extent that either one or all of the mechanisms advanced by Wilson et al. (1994) played a significant role in reducing muscular strength. Moreover, because Taylor et al. (1990) showed an increased length following stretching, it is very probable that the contractile components were at less than optimal point on the force-length curve when they began transmitting force to the bone.

As an alternative explanation to a change in musculotendinous stiffness, the 1RM performance decrement might be related to the response of muscle or joint proprioceptors (e.g., Golgi tendon organs and low threshold pain receptors) to a sustained stretch. Golgi tendon organs respond to stretch or tension by producing a reflexive inhibition (autogenic inhibition) of both the muscle being stretched and its synergists (Moore, 1984). Similarly, stimulating pain receptors located in the muscles, tendons, and joint capsules can also inhibit the neural pathways responsible for muscle activation (Moore, 1984). Because the participants experienced repeated bouts of sustained stretching at their pain threshold, it is possible that sufficient autogenic inhibition was present to diminish the number of available motor units, thereby limiting force production. The likelihood of motor-unit inhibition being the predominant mechanism, however, is questionable. Using the H reflex to measure the excitability of the triceps surae motor-unit neuron pool, Guissard, Duchateau, and Hainaut (1988) obtained evidence to suggest that autogenic inhibition is limited to the duration of the stretching maneuver. Thigpen et al. (1985), however, showed the H reflex to remain depressed after the triceps surae muscle group was released from a sustained stretch, although the duration of time elapsed before the poststretch measurements were taken was not reported. Because our participants were allowed 10 min of rest after completing the last stretching exercise, we do not consider autogenic inhibition a likely mechanism to account for our findings. It is suggested, therefore, that the decrease in strength is related to a decrease in musculotendinous stiffness, rather than inhibition of muscle activation.

Regardless of the mechanism responsible, however, this study does indicate that maximal knee-flexion and extension 1RM can be reduced by engaging in a thor-
ough bout of acute stretching. Care, however, should be used in extending these results to all types of stretching activities. This study looked at a specific stretching regimen which incorporated active and passive stretching of both the agonist and antagonist muscles around three joints for 20 min. It is possible that a program which stretched only a single muscle group either actively or passively alone for a shorter time might not yield the same results. On the other hand, two recent presentations (Fowles & Sale, 1997; Nelson, Cornwell, & Heise, 1996) at national symposiums would suggest that the findings of this study may be generalizable to a variety of acute stretching activities. Obviously, further work is required to establish the mechanism or mechanisms responsible for these findings. Nevertheless, it is suggested that intense static stretching of the prime-mover muscles of a particular skill should not be undertaken just prior to any event in which success is related to maximal strength output.

References


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