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Acute Muscle Stretching Inhibits Muscle Strength Endurance Performance

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Abstract. Nelson, A.G., J. Kokkonen, and D.A. Arnall. Acute muscle stretching inhibits muscle strength endurance performance. *J. Strength Cond. Res. 19(2):338–343. 2005.*—Since strength and muscular strength endurance are linked, it is possible that the inhibitory influence that prior stretching has on strength can also extend to the reduction of muscle strength endurance. To date, however, studies measuring muscle strength endurance poststretching have been criticized because of problems with their reliability. The purpose of this study was twofold: both the muscle strength endurance performance after acute static stretching exercises and the repeatability of those differences were measured. Two separate experiments were conducted. In experiment 1, the knee-flexion muscle strength endurance exercise was measured by exercise performed at 60 and 40% of body weight following either a no-stretching or stretching regimen. In experiment 2, using a test-retest protocol, a knee-flexion muscle strength endurance exercise was performed at 50% body weight on 4 different days, with 2 tests following a no-stretching regimen (RNS) and 2 tests following a stretching regimen (RST). For experiment 1, when exercise was performed at 60% of body weight, stretching significantly ($p < 0.05$) reduced muscle strength endurance by 24%, and at 40% of body weight, it was reduced by 9%. For experiment 2, reliability was high (RNS, intraclass correlation = 0.94; RST, intraclass correlation = 0.97). Stretching also significantly ($p < 0.05$) reduced muscle strength endurance by 28%. Therefore, it is recommended that heavy static stretching exercises of a muscle group be avoided prior to any performances requiring maximal muscle strength endurance.

Key Words. muscular endurance, flexibility, stretching, warm-up

Introduction

Flexibility (joint range of motion) is promoted as an important component of physical fitness (28). It is widely conjectured that increasing flexibility will promote better performances and reduce the incidence of injury (30, 32). Consequently, stretching exercises designed to enhance flexibility are regularly included in both the training programs and in the pre-event warm-up activities of many athletes (11, 14).

Notwithstanding the widespread acceptance and use of stretching exercises as a major component of pre-event activities, the purported benefits that stretching has on performance and injury prevention have come into question in several review papers (11, 13, 18, 35). In addition, recent research has established an adverse effect of acute static stretching on various different maximal performances. Pre-event stretching has demonstrated an inhibitory effect on maximal force or torque production (3, 4, 7, 9, 20, 24, 26, 27), vertical jump performance (5, 6, 23, 39, 40), and running speed (25, 31). This paradox between accepted dogma and current research places a difficult decision on coaches and athletes. Do they include flexibility exercises in their pre-event activities and risk the loss of maximal performance, or do they drop the flexibility exercises and increase the risk of injury? Since many sporting events do not require maximum force production, it would appear prudent to err toward the continuation of pre-event stretching. On the other hand, if acute stretching adversely affects other performance variables, it might become more advantageous to eliminate pre-event stretching. One additional performance variable that might be negatively affected by acute stretching is muscular strength endurance.

Muscular strength endurance (i.e., the number of consecutive repetitions a person can lift a specified weight or the length of time a person can hold a specified weight) has long been associated with maximal muscular strength (i.e., 1 repetition maximum [1RM]). In 1950, Tuttle et al. (34) reported a high correlation between grip strength and muscle strength endurance indices. Five years later, Tuttle et al. (33) reported similar correlations between maximum strength and muscle strength endurance for both back and leg strength. Then, in 1969, McGlynn (22) found a high and significant correlation between strength and muscle strength endurance both before and after a 20-day strength training program. In addition, McGlynn (22) found that an untrained control group maintained similar correlations between strength and muscle strength endurance at both the beginning and the end of the 20-day training period. More recent studies have shown that the relationship between strength and muscle strength endurance still exists. For instance, strength training studies continue to show a strong relationship between strength and muscle strength endurance in both women (15) and children (8). Moreover, losses of strength are accompanied by losses in muscle strength endurance (17).

Since there is a long-established link between strength and muscle strength endurance, it is reasonable to suppose that the inhibitory influence that prior stretching has on strength and power can also result in a decrement in muscle strength endurance. Unfortunately, studies to date have not been entirely successful in establishing such a link. In a presentation at the American College of Sports Medicine 2001 Annual Meeting, Kokkonen et al. (19) presented data showing a decline in muscle strength endurance following stretching. These results were strongly criticized, however, because the reported decline in the number of lifts was thought to be

TABLE 1. Subjects' descriptive characteristics.*

Gender	Age (y)	Weight (kg)	Height (cm)
Experiment 1 (n = 22)			
Men (n = 11)	25 ± 4	85 ± 14	181 ± 7
Women (n = 11)	21 ± 2	60 ± 11	165 ± 8
Experiment 2 (n = 23)			
Men (n = 9)	24 ± 1	86 ± 11	183 ± 9
Women (n = 14)	22 ± 2	63 ± 10	166 ± 5

* Values are mean ± *SD*.

within the expected day-to-day variation. The validity of this criticism was shown in a study by Laur et al. (21). This study examined the effect of stretching on muscle strength endurance in 2 groups for 2 days. On day 1, the maximum lifts at 60% 1RM poststretching was measured in group 1, while group 2 performed the same test without prior stretching. On the second day, the stretch treatment was reversed, and group 1 had a significant increase in the number of lifts following the no-stretch treatment. However, the number of lifts for group 2 on the second day (their stretch treatment day) was also greater than the number of lifts performed on day 1.

Notwithstanding the questions of reliability, it remains possible for acute stretching to induce muscle strength endurance decrements along with strength decrements. Therefore, the purpose of this study was to determine the influence of an acute stretching activity on maximal muscle strength endurance performance. Additionally, this study was designed to determine the repeatability of any measured differences. Specifically, the investigation concentrated on whether or not the acute stretching of hip, thigh, and calf muscles would alter the maximum number of knee-flexion repetitions that a person could perform with a specific weight.

METHODS

Experimental Approach to the Problem

As mentioned above, reliability (or repeatability) has been a major problem with previous work. Therefore, 2 different experiments were conducted to ascertain if prior stretching could cause muscle strength endurance decrements. The first experiment assumed that if prior stretching negatively influenced muscle strength endurance, then that negative influence would be independent of workload. Therefore, for the first study, the subjects in the study by Kokkonen et al. (19) were tested at an additional workload. The second study followed traditional reliability testing protocols and used a test-retest protocol.

Subjects—Experiment 1

The subjects in experiment 1 consisted of 22 college students (11 women and 11 men) enrolled in professional physical education classes. All of the subjects were physically active, but, at the time of the study, none was engaged in any regular or organized stretching and/or resistance training activity. Descriptive characteristics of the subjects are tabulated in Table 1. None of the individuals was aware of the results of any of the aforementioned studies on acute stretching. Moreover, when asked, "Yes or no, is stretching before doing any weight lifting beneficial?", all of the individuals replied *yes*. Approval from the Brigham Young University-Hawaii (BYU-HI) institutional review board and both written and oral consents from each individual were obtained before the experiment commenced.

Subjects—Experiment 2

The subjects in experiment 2 consisted of 23 college students enrolled in professional physical education classes (14 women and 9 men). All of the subjects were physically active, but, at the time of the study, none was engaged in any regular or organized stretching and/or resistance training activity. Descriptive characteristics of these subjects are also tabulated in Table 1. None of the individuals was aware of the results of any of the aforementioned studies on acute stretching and had not participated in experiment 1. Moreover, when asked, "Yes or no, is stretching before doing any weight lifting beneficial?", all of the individuals replied *yes*. Approval from the BYU-HI institutional review board and both written and oral consents from each individual were obtained before the experiment commenced.

Experimental Overview—Experiment 1

Experiment 1 began with each subject doing repetitious prone-knee flexion on 2 successive days. This initial experiment was performed using a workload equal to approximately 60% of the person's body weight. As mentioned above, the experiment was repeated 3–4 months later, this time using a workload equal to about 40% of the person's body weight. Thus, each subject reported to the laboratory a total of 4 times (i.e., 60% load on days 1 and 2 and 40% load on days 3 and 4). On each day, one of two treatments preceded the repeated knee-flexion lifts. The 2 treatments were either 10 minutes of quiet sitting (NS) or 15 minutes of passive static stretching of the hip, thigh, and calf muscle groups (ST). NS and ST were assigned at random, so that one-half of the subjects did NS on days 1 and 3. On days 2 and 4, these subjects did the ST protocol. The other half of the subjects performed ST on the first and third testing days. Those individuals who did ST on days 1 and 3 did NT on days 2 and 4.

To ascertain whether alterations in joint range of motion occurred following either NS or ST, each subject did a sit-and-reach test on an Acuflex I sit-and-reach box before and after each treatment. Thus, when the subjects entered the laboratory on each testing day, they did the following activities in order: sit-and-reach test 1, NS or ST, sit-and-reach test 2, and knee-flexion muscle strength endurance test.

Experimental Overview—Experiment 2

For experiment 2, each subject did repetitious prone-knee flexion for 4 days. The knee-flexion muscle strength endurance test was performed using a workload equal to about 50% of the person's body weight. To limit the subjects' recall of any previous performance and lessen the effect of any muscle soreness, 1 week intervened between each experimental day. As with experiment 1, one of two treatments preceded each day's repeated knee-flexion lifts. Again, the 2 treatments were either 10 minutes of quiet sitting (RNS) or 15 minutes of passive static stretching of the hip, thigh, and calf muscle groups (RST). The order in which each subject did the RNS and RST was set so that any activity-based learning had a greater chance of improving the RNS performance. On day 1, each subject did the RNS protocol. On days 2 and 3, everyone performed the RST, and on day 4, the RNS treatment was repeated.

As before, alterations in joint range of motion were documented by having each subject do a sit-and-reach test on an Acuflex I sit-and-reach box before and after each treatment. Thus, when the subjects entered the laboratory on each testing day, they did the following activities in order: sit-and-reach test 1, RNS or RST, sit-and-reach test 2, and knee-flexion muscle strength endurance test.

Stretching Protocol—Experiments 1 and 2

The stretching protocol was the same for both experiments. The stretching programs (ST and RST) consisted of 2 different static stretching activities designed to stretch the major muscles involved in knee flexion. A sit-and-reach test was the first stretching exercise. The subjects sat on the floor with their legs extended and then lowered their heads toward their knees. For the second activity, a heel cord stretch was performed. To do this, the subjects first stood with 1 foot flat on the floor and the other foot placed on a block so that the ball of the foot was about 10 cm above the heel. The subjects would then lean forward until maximum dorsiflexion was achieved and until noticeable tension was felt in the calf.

The subjects first performed 4 unassisted repetitions of the sit-and-reach test. Once this was completed, 4 repetitions of the heel cord stretch were performed. After completing the first set of heel cord stretches, a second set of 4 repetitions of the sit-and-reach test was performed. This time, however, the stretching was done with assistance from one of the investigators. Finally, a second set of 4 repetitions of the heel cord stretch was performed. For each of the exercises, the subject would assume the appropriate position and then lean or lower as far as possible, thus inducing significant extension in the appropriate musculature. On feeling the stretch, the person would hold the position for 30 seconds. After the 30 seconds, the person would relax for 15 seconds and then repeat the activity 3 more times with a 15-second recovery period between each of the 30 seconds of stretching. The stretching exercises were usually completed in 15 minutes. Following the stretching bout, the subject would relax for 10 minutes before repeating the sit-and-reach test.

Muscle Strength Endurance Test Protocol—Experiments 1 and 2

The knee-flexion muscle strength endurance test for both experiments was performed in the prone position using a Nautilus knee-flexion machine. Prior to the test, the full knee-flexion range of motion was determined. The subjects would move the device unweighted until they could no longer flex their knees. Lines marking this position were placed on both the stationary and moving parts of the machine, and subsequent lifts were not counted unless these marks were in alignment. To ensure that all lifts were performed at the same rate, a metronome set at 90 $b \cdot min^{-1}$ was placed near the individual's head. Each person was instructed to either raise or lower the weight with each beat (flexion and extension were completed in approximately 2 seconds). Each subject had an initial practice with the metronome separate from the test to ensure that the lifts could be made in synchrony with the metronome. For all of the tests, the resistance was set to the nearest (but not exceeding) 11.1 N (2.5 lb) of 60, 50, or 40% of the person's body weight.

Table 2. The effects of stretching on sit-and-reach in experiment 1.†‡

Treatment	Pre (cm)	Post (cm)	Mean difference (cm)
60% trial			
NS (n = 22)	37.2 ± 6.3	37.1 ± 6.5	−0.1 ± 1.0
ST (n = 22)	36.2 ± 6.9	42.0 ± 5.3	5.7 ± 3.6*
40% trial			
RNS (n = 22)	38.6 ± 5.9	38.5 ± 5.6	−0.1 ± 2.0
RST (n = 22)	38.2 ± 5.6	42.7 ± 5.1	4.5 ± 4.8*

* Indicates a significant pre-to-post difference, $p < 0.05$.
† Values are mean ± *SD*.
‡ NS = 10 minutes of quiet sitting; ST = 15 minutes of passive static stretching of the hip, thigh, and calf muscle groups.

When (a) the person was situated correctly within the apparatus, (b) the correct weight had been loaded, and (c) the metronome had started, the person was instructed to lift and lower the weight through the full range of motion in time with the metronome using both legs. Subjects continued lifting until they could no longer lift the weight to the predetermined mark 3 times in succession. At that point, the total number of correctly completed lifts was recorded, and subjects were removed from the apparatus. The number of correct lifts that each subject made at each session was not disclosed until after the study was completed.

Statistical Analyses—Experiment 1

A 2-way (treatment vs. pre-post) repeated-measures analysis of variance (ANOVA) was used for analysis of the sit-and-reach tests (60 and 40% tested separately). Significance was set at $p \leq 0.05$. Post hoc ANOVA analysis involved, when appropriate, the use of Tukey's protected t-test. The muscle strength endurance measurements within a given workload (i.e., 60 or 40%) were analyzed using paired t-tests. Again, the level of significance was set at $p \leq 0.05$.

Statistical Analyses—Experiment 2

The reliability of both the repeated RNS muscle strength endurance measures and the repeated RST muscle strength endurance measures were determined using an intraclass correlation coefficient. A 3-way (treatment vs. pre-post vs. test day) repeated-measures ANOVA was used for analysis of the sit-and-reach tests. The muscle strength endurance measurements were analyzed using a 2-way (treatment vs. test day) repeated-measures ANOVA. Significance was set at $p \leq 0.05$. Post hoc ANOVA analysis involved, when appropriate, the use of Tukey's protected t-test.

Results

Range of Motion—Experiment 1

The influence of the stretching program on the sit-and-reach test for both exercises performed at 60 and 40% of body weight is shown in Table 2. For the exercise performed at 60% of body weight, the main effect for treatments ($F(1, 21) = 21.9$, $p < 0.0001$, $\hat{\omega}^2 = 0.25$), the main effect for pre-post ($F(1, 21) = 55.0$, $p < 0.0001$, $\hat{\omega}^2 = 0.29$)

TABLE 3. The effects of stretching on knee-flexion muscle strength endurance in experiment 1.†‡

Workload	NS (lifts)	ST (lifts)	Mean difference (lifts)
60% body weight (n = 22)	14.4 ± 4.0	10.9 ± 4.2	3.5 ± 3.1*
40% body weight (n = 22)	31.6 ± 12.1	29.3 ± 12.5	2.3 ± 4.3*

* Indicates a significant pre-to-post difference, $p < 0.05$.
† Values are mean ± *SD*.
‡ Abbreviations are explained in the third footnote to Table 2.

TABLE 4. The effects of stretching on sit and reach in experiment 2.†‡

Trial—Condition	Pre (cm)	Post (cm)	Mean difference (cm)
Trial 1—RNS (n = 23)	32.8 ± 8.6	33.4 ± 7.8	0.2 ± 1.9
Trial 2—RST (n = 23)	33.9 ± 8.5	40.0 ± 6.5	6.0 ± 3.3
Trial 3—RST (n = 23)	34.8 ± 7.5	40.5 ± 6.5	5.7 ± 2.7
Trial 4—RNS (n = 23)	33.4 ± 7.8	33.3 ± 7.4	−0.1 ± 1.8

* Indicates a significant pre-to-post difference, $p < 0.05$.
† Values are mean ± *SD*.
‡ RNS = 10 minutes of quiet sitting; RST = 15 minutes of passive static stretching of the hip, thigh, and calf muscle groups.

and the interaction between treatment and pre-post ($F(1, 21) = 49.5$, $p < 0.0001$, $\acute{\omega}^2 = 0.41$) were significant. Post hoc analysis showed that all of the significance was due to the subjects who engaged in the leg stretching program having had a significant mean increase in the sit-and-reach test. For the exercise performed at 40% of body weight, the main effect for treatments ($F(1, 21) = 26.7$, $p < 0.0001$, $\acute{\omega}^2 = 0.26$), the main effect for pre-post ($F(1, 21) = 59.0$, $p < 0.0001$, $\acute{\omega}^2 = 0.30$), and the interaction between treatment and pre-post ($F(1, 21) = 65.8$, $p < 0.0001$, $\acute{\omega}^2 = 0.43$) were all significant. Again, post hoc analysis showed that all of the significance was due to the subjects who engaged in the leg stretching programs having had a significant mean increase in the sit-and-reach test.

Muscle Strength Endurance—Experiment 1

The results of the muscle strength endurance test at both 60 and 40% of body weight are presented in Table 3. Following the ST treatment, the average number of lifts using 60% of body weight was significantly less ($t(21) = 5.23$, $p < 0.0001$, $\acute{\omega}^2 = 0.37$) than the NS average number of lifts at the same workload (average decline = 24.4%). Likewise, the ST program had a negative influence on the average number of lifts at 40%, with the average number of lifts following ST averaging a significant ($t(21) = 2.41$, $p < 0.025$, $\acute{\omega}^2 = 0.10$) 9.8% less than the average number of lifts following the NS program.

Reliability—Experiment 2

The test-retest reliability for both the RNS and RST test days was high. The intraclass coefficient for the 2 days of RNS measurements was $R = 0.941$, and for the 2 days of RST, it was $R = 0.970$.

Range of Motion—Experiment 2

The influence of the stretching program on the sit-and-reach test for experiment 2 is shown in Table 4. The main effect for treatments ($F(1, 22) = 102.2$, $p < 0.0001$, $\acute{\omega}^2 = 0.07$), the main effect for pre-post ($F(1, 22) = 94.2$, $p < 0.0001$, $\acute{\omega}^2 = 0.03$), and the interaction between treatment and pre-post ($F(1, 22) = 81.7$, $p < 0.0001$, $\acute{\omega}^2 = 0.03$) were significant. The main effects for days and all of the days' interactions (days × treatments, days × pre-post, and days × treatments × pre-post) were not significant ($p > 0.05$). Post hoc analysis showed that all of the significance was due to the subjects who engaged in the leg stretching program having had a significant mean increase in the sit-and-reach test.

TABLE 5. The effects of stretching on knee-flexion muscle strength endurance in experiment 2.†‡

Trial—Condition	No. of lifts
Trial 1—RNS (n = 23)	15.7 ± 5.9
Trial 2—RST (n = 23)	11.6 ± 6.0*
Trial 3—RST (n = 23)	11.7 ± 6.1*
Trial 4—RNS (n = 23)	16.0 ± 5.9

* Indicates an RST value that is significantly greater ($p < 0.05$) than either RNS values.
† Values are mean ± *SD*.
‡ Abbreviations are explained in the third footnote to Table 4.

Muscle Strength Endurance—Experiment 2

The results of the muscle strength endurance test performed in experiment 2 are presented in Table 5. The main effect for treatments ($F(1, 22) = 50.2$, $p < 0.0001$, $\acute{\omega}^2 = 0.11$) was significant. As expected from the reliability tests, the main effects for days and the treatment × days interaction were not significant ($p > 0.05$). Post hoc analysis showed that all of the significance was due to the subjects who engaged in the leg stretching program having had a significant mean 28% decrease in the number of lifts.

DISCUSSION

The primary purpose of this investigation was to determine the effect of acute muscle stretching on muscle strength endurance. A second purpose was to determine the repeatability of any measured differences. The main finding was a significant and repeatable decrease in knee-flexion muscle strength endurance performance following an acute stretching treatment. The data clearly indicate, therefore, that a specific regimen of acute stretching can inhibit the muscle strength endurance of the knee flexors engaged in a particular task.

Research into the mechanism of fatigue during volitional activities has demonstrated that impairment in both muscular mechanisms and neural mechanisms can develop when these activities lead to fatigue (10, 16). Even though the possibility for impairment from both mechanisms exists, the decreased number of lifts, post-stretching, is most likely due to neurological impairment. Research into neuronal fatigue during the performance of a fatiguing task indicates that fatigue is manifested by a reduction in excitatory inputs (10, 16). Moreover, this decrease in excitation is compensated for by the progressive recruitment of new motor units, with the activation of both the initial and the subsequent motor units following a specific and unalterable pattern (1). Using electromyography and twitch interpolation techniques, several researchers have determined that pre-event stretching causes a decrease in muscle activation (3, 4, 9). Thus, it is possible that the stretching regimen placed a proportion of the motor units into a fatiguelike state prior to the initiation of the muscle strength endurance task. Placing specific motor units into a fatiguelike state would decrease the pool of motor units available for activation, and this loss of motor units from the pool of available motor units could hasten fatigue and lead to a decrease in performance.

On the other hand, stretching has the capacity to induce other changes that could have, at the least, a contributory influence on muscle strength endurance. First, Evetovich et al. (7) determined that the poststretch force decrement is related to a decrease in muscle stiffness. Moreover, Wilson et al (37) demonstrated that reduced stiffness can result in a reduction of force transmission between the muscle and the skeletal system. Hence, it is possible that to compensate for the decrease in force production, a greater activation/stimulation rate was required, and this, in turn, resulted in a faster rate of neural fatigue. Second, a few researchers have demonstrated that blood flow through a muscle can be impaired during the time that the muscle is being stretched (29, 38). Force reductions have been reported during periods of partial ischemia, and this force reduction is attributed either to a lower oxygen supply and/or impaired removal of metabolic by-products (12). Because the fatigue test was performed after the stretching, blood flow was probably near normal. Nevertheless, the repeated periods of ischemia could have elevated the level of waste metabolites within the muscle. So, when the muscle started contracting again, the waste concentration was closer to the critical level that triggers inhibition of muscle contraction. Finally, the increased fatigue could be related to altered Ca^{++} kinetics. Armstrong et al. (2) reported an increase in Ca^{++} influx from extracellular spaces into the cells of isolated rat soleus muscle undergoing static stretching, and this influx of Ca^{++} coincided with a 63% decrease in maximal twitch tension. One of the theories behind fatigue is that elevated intracellular Ca^{++} levels cause fatigue by preventing Ca^{++} release from the sarcoplasmic reticulum (36). Thus, it is possible that, in this study, the repeated stretches elevated the resting Ca^{++} levels, and this elevated level of Ca^{++} hastened fatigue.

Practical Applications

Notwithstanding the significant results obtained in this study, these results do not imply that any or all stretching regimens will reduce the endurance of the whole gamut of physical activities. Rather, this study indicates that an intense stretching protocol will reduce the endurance of "1 set to failure" activities. There are an infinite number of possible stretching protocols and exercise tasks, and it is very likely that with some of these combinations, no negative relationship exists. It should be noted that, to date, we are aware of only 2 studies that have investigated the effect of prior stretching on tasks that require multiple repetitive activities (25, 31). Both of these studies reported a reduced sprint speed, and it is possible the mechanisms involved in this study were similar to those in the other 2 studies. Nevertheless, this study shows that a possible outcome following a stretching program is a loss of muscle strength endurance. Moreover, the likelihood of a stretch-induced loss of muscle strength endurance increases with both the intensity of the stretch and the intensity of the endurance task.

Probably the greatest impact of this study lies with the timing of stretching within a workout program. To maintain a progressive overload during weight training, the classic recommendation is to increase the weight at the point that fatigue no longer appears during the specific lift's last repetition of the final set. Stretching prior to lifting could induce a "false-negative" experience and delay the individual from progressing to a high load. Moreover, if a person is using a 1 set to failure protocol, prior stretching could reduce the number of lifts and limit the total benefit that could have been achieved. Finally, if the hypothesized neural inhibition is occurring, then prior stretching would prevent a set pool of motor units from ever being activated, and thus, a certain portion of the muscle would never get trained.

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