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Duration of Maintained Hamstring Flexibility After Cessation of an Acute Static Stretching Protocol

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Objective: Increased muscle flexibility from static stretching is supported by the literature, but limited research has assessed the duration of maintained flexibility gains in knee joint range of motion after same-day static hamstring stretching. The purpose of our study was to determine the duration of hamstring flexibility gains, as measured by an active knee-extension test, after cessation of an acute static stretching protocol.

Design and Setting: All subjects performed 6 active warm-up knee extensions, with the last repetition serving as the baseline comparison measurement. After warm-up, the experimental group performed 4 30-second static stretches separated by 15-second rests.

Subjects: Thirty male subjects (age = 19.8 ± 5.1 years, ht = 179.4 ± 18.7 cm, wt = 78.5 ± 26.9 kg) with limited hamstring flexibility of the right lower extremity were randomly assigned to control and experimental groups.

Measurements: Postexercise active knee-extension measurements for both groups were recorded at 1, 3, 6, 9, 15, and 30 minutes.

Results: Tukey post hoc analysis indicated significant improvement of knee-extension range of motion in the experimental group that lasted 3 minutes after cessation of the static stretching protocol. Subsequent measurements after 3 minutes were not statistically different from baseline. A dependent *t* test revealed a significant increase in knee-extension range of motion when comparing the first to the sixth active warm-up repetition.

Conclusions: Our results suggest that 4 consecutive 30-second static stretches enhanced hamstring flexibility (as determined by increased knee-extension range of motion), but this effect lasted only 3 minutes after cessation of the stretching protocol. Future research should examine the effect of other stretching techniques in maintaining same-day flexibility gains.

Key Words: knee extension, knee range of motion, duration of flexibility gains

Hamstring strains are a common athletic injury with a tendency to recur.[1–3] Lack of flexibility has been suggested as a predisposing factor to hamstring strains.[4–6] Clinicians have generally considered flexibility training to be an integral component in the prevention and rehabilitation of injuries, as well as a method of improving one's performance in daily activities and sports.[7–13] As clinicians, we often provide stretching protocols to athletes with the expectation that flexibility gains will last long enough to have at least a temporary beneficial effect.[14,15] For athletes to take advantage of flexibility gains, it would be useful to know how long these effects last. For example, the athlete who performs a series of static stretches and then attends a team meeting or sits on the sideline for 30 minutes may not retain the effects of stretching when practice begins or upon entering a contest.

Previous research examining the hamstring complex has shown that stretching increases one's range of motion, regardless of whether the stretching technique performed is ballistic, static, proprioceptive neuromuscular facilitation, or modified proprioceptive neuromuscular facilitation techniques.[9,12–14,16–24] However, only 3 of these studies[14,20,22] measured how long the hamstring gains were maintained, and all 3 assessed gains after multiple-day stretching programs. No study has addressed the duration of flexibility gains immediately after cessation of a single, same-day series of acute static stretches. Thus, the purpose of our study was to measure the duration of hamstring flexibility gains after cessation of a same-day static stretching protocol.

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METHODS

Thirty male cadets from a collegiate military institute (age = 19.8 ± 5.1 years, ht = 179.4 ± 18.7 cm, wt = 78.5 ± 26.9 kg) participated in this study on a volunteer basis. All subjects were free from injury to the hamstrings and low back for the previous 6 months. Additionally, subjects lacked at least 20° of full extension as measured with a universal goniometer during an active knee-extension (AKE) test. Twenty degrees was selected to ensure a clinical limitation that would potentially respond to the subjects' participation in a stretching program. The study was approved by the institutional review board at the University of Virginia, and all subjects read and signed an informed consent form before participating.

Testing and Treatment Sequence

The 30 subjects were randomly assigned to either the control group (n = 15) or the experimental group (n = 15). Before baseline measures, subjects in both groups performed 6 active knee extensions, with a 60-second rest between repetitions. The first 5 AKEs served as warm-ups to reduce potential effects from multiple AKEs.[25] The sixth AKE served as the baseline trial.

The experimental group performed 4 30-second static stretches with a 15-second rest between stretches. Immediately after the last stretch, subjects were positioned for posttesting. Control group subjects remained supine on the evaluation table for the same duration (3 minutes) taken to stretch the experimental group. For both groups, an additional minute was used to reposition the hip and knee flexion angles before the first posttest measurement. Posttest measurements were taken at 1, 3, 6, 9, 15, and 30 minutes after cessation of the static stretching protocol. One measurement was recorded at each time interval.

Preparticipation Screening

A preparticipation screening of hamstring flexibility was conducted using the AKE test (180° = full extension) and measured using a clear plastic universal goniometer with 1° increments. The stationary arm of the goniometer was placed along the lateral femur, and the moving arm was aligned with the lateral fibula. Subjects extended the knee to its limit of motion. The number of degrees from full extension was recorded.

Subject Positioning

For flexibility measures, subjects were positioned supine on an examination table under a polyvinylchloride (PVC) pipe frame apparatus (diameter = 1.6 cm, crossbar length = 66 cm, height = 50 cm, base length = 64 cm) for all AKE measurements (Figure 1). Subjects stabilized the apparatus by holding on to the upright pipes that were on either side of the hips. The PVC crossbar helped subjects maintain active right hip positioning of 90° of flexion during the AKE movement.

We used a universal goniometer to measure a right hip angle of 90°. Once this hip angle was determined, the PVC apparatus was positioned to allow the distal anterior thigh to maintain contact with the overlying crossbar. Throughout the procedure, the left hip remained at 0° of flexion. After hip positioning, we used the goniometer to position the knee at 90° of flexion. Once this knee angle was achieved, we placed a gravity-assisted protractor (Empire Level Manufacturing Corp, Milwaukee, WI) on the lateral aspect of the leg with a hook-and-loop strap 2.54 cm below the fibular head (Figure 1) and set it to read 0°. Knee joint range of motion was reported in degrees from full extension (ie, 180°).

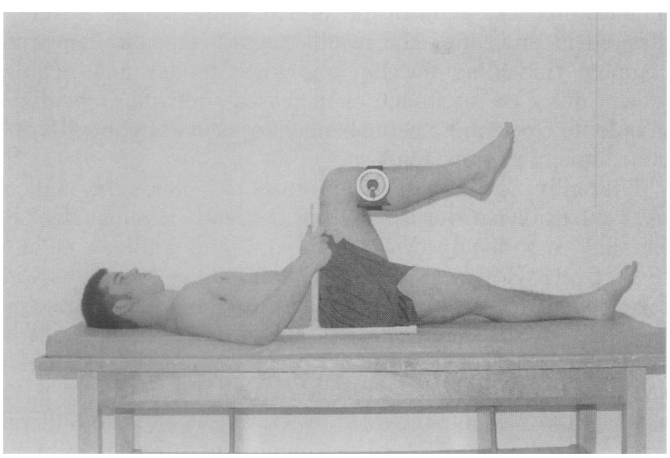

Figure 1. Active knee-extension positioning.

Flexibility Assessment

Before testing, each subject was positioned lying on the left side on the examination table for bony landmark identification. The right hip and knee were flexed to 90°, simulating the position of the AKE test. We used a black felt-tip marker to draw a circle around the lateral femoral epicondyle, the head of the fibula, and the lateral malleolus of the right leg. Once the subject was placed in the supine AKE position, we palpated the circles to verify that they identified the desired bony landmarks. This procedure was done to ensure that the same reference points were used for hip and knee repositioning over repeated measures.

After placement of the protractor on the proximal tibia, each subject actively extended his lower leg. The ankle remained in a relaxed position that was comfortable to the subject. When the subject could not extend his lower leg any further without his thigh's moving away from the crossbar, he informed the examiner and held that position until a measurement was taken. The protractor was not removed from its position throughout the AKE pretest or posttest period. Protractor adjustment to read 0° when the knee was flexed to 90° was performed as needed. Subjects kept the right hip and knee flexed with the foot flat on the table between trials. We used the goniometer to reposition the hip to 90° of flexion for each trial.

Stretching Protocol

The experimental group received instruction in performing the static stretch. All stretching was performed with the right lower extremity. Corrective verbal feedback was given throughout the stretching protocol to ensure that proper technique was maintained. The same investigator gave all instruction and feedback.

The stretch was performed standing, facing a padded evaluation table with the heel of the right limb placed on the edge of the table in relaxed plantar flexion (Figure 2). Neutral right hip rotation was maintained by keeping the foot pointed straight up. The standing leg was positioned so that the left foot was perpendicular to the table. The subject was then instructed to bend forward at the waist. During the stretch, the subject attempted to maintain a flat back with the pelvis in relative anterior rotation, neutral position of the head, and full extension of the stretched leg. Each subject bent forward and stopped when a stretch sensation was experienced in the posterior thigh. This position was maintained for 30 seconds, measured with a wall clock positioned in front of the subject. Between stretches, subjects were allowed to remove the leg from the table and flex the knee.

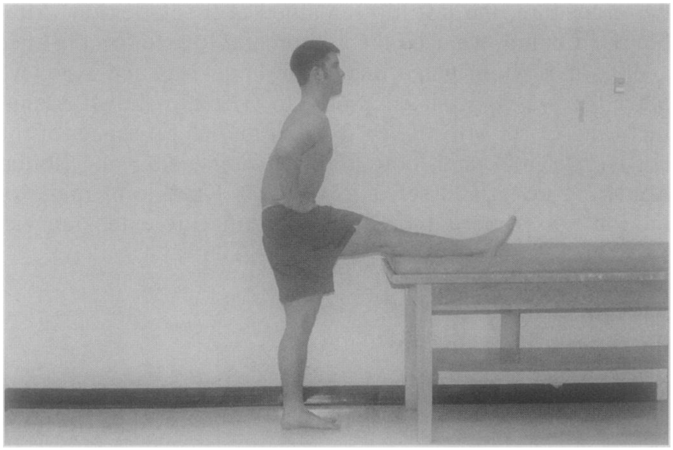

Figure 2. Static hamstring stretch positioning.

Knee Angles (Mean ± SD) for Control and Static Stretch Groups

Time (min)	Control (°)	Static Stretch (°)
Baseline 0	134.6 ± 13.8	135.6 ± 11.2
Poststretch 1	131.7 ± 14.1	142.4 ± 13.2*†
3	131.1 ± 14.3*‡	141.2 ± 14.3*§
6	129.1 ± 15.1*	138.3 ± 14.1‖
9	128.5 ± 14.0*	135.9 ± 14.2
15	128.1 ± 14.4*	134.5 ± 12.9
30	127.1 ± 13.7*	134.1 ± 13.6

*Significantly different from group baseline.

†Knee angle at 1 minute significantly greater than at 6, 9, 15, and 30 minutes.

‡Knee angle at 3 minutes significantly greater than at 30 minutes.

§Knee angle at 3 minutes significantly greater than at 6, 9, 15, and 30 minutes.

‖Knee angle at 6 minutes significantly greater than at 15 and 30 minutes.

Reliability

Intratester reliability and standard error of measurement were determined for the AKE test. Twelve test subjects were randomly chosen ($n = 5$ control, $n = 7$ experimental subjects). A total of 6 AKEs were performed as previously described in the testing and treatment sequence. The sixth repetition was recorded and compared with the final (sixth) AKE performed in the pretest, which served as the second set of data. Subjects were tested on 2 separate days and at similar times to minimize diurnal effects.

We used the intraclass correlation coefficient 2,1 to determine intratester reliability[26] and the standard error of measurement to determine the precision of measurement.[27] The intraclass correlation coefficient and standard error of measurement were 0.96 and 2.29°, respectively.

Data Analysis

We used a mixed-model analysis of variance (ANOVA) with 1 between (group) and 1 within (time) factor to determine whether there were significant differences in knee-extension angles. The Tukey honestly significant difference (HSD) post hoc analysis was employed to determine where significant differences occurred. A dependent *t* test was used to determine whether a significant difference existed between the first and sixth warm-up AKEs. The α level was set a priori at $P < .05$ for all analyses.

RESULTS

The mean angle of knee-flexion measurements for pretest and posttest active knee extensions are presented in the Table. The repeated-measures ANOVA revealed a significant group-by-time interaction ($F_{6,168} = 9.93$, $P < .001$). Tukey HSD post hoc analyses revealed that significant increases in knee extension were maintained in the experimental group at 1 and 3 minutes after cessation of the stretching protocol and then gradually decreased over time. The control group's knee extension was decreased from baseline at 3 minutes and remained decreased throughout testing. The ANOVA also revealed a significant main effect for time ($F_{6,168} = 23.49$, $P < .001$); however, post hoc testing failed to determine when this occurred. The dependent *t* test revealed a 5.9° increase in knee extension ($t_{29} = 8.46$, $P < .001$) from the first AKE (129.2° ± 12.2°) to the sixth AKE (135.1° ± 12.3°).

DISCUSSION

Our major finding was that statistically significant knee-extension range-of-motion gains of 6.8° and 5.6° were maintained at 1 and 3 minutes poststretching, respectively. The range-of-motion gains returned to the baseline by 6 minutes after stretching.

The inability to maintain significant knee-extension angles beyond 3 minutes in our study suggests that a temporary creep effect occurred in which the viscoelastic component of the hamstrings was not deformed enough to produce a permanent change.[28,29] With respect to the contractile component of muscle, Bohannon[17] proposed that the inability of the hip joint to maintain significant flexion angles after hamstring stretching was due to temporary sarcomere lengthening. Temporary sarcomere lengthening may have occurred with our hamstring stretch subjects.

Bohannon[17] recorded 1 of 2 follow-up measurements in an elapsed time frame similar to that incorporated in our study. Over the course of 3 consecutive days of 8-minute passive loading, Bohannon recorded statistically significant ($P < .01$) maintained angles of hip flexion of 3.0° (day 1), 3.3° (day 2), and 2.9° (day 3) at 10 minutes postloading. Ten minutes after cessation of an 8-minute static stretch, Bohannon[17] recorded a statistically significant ($P < .01$) maintained angle of hip flexion of 3.0°. The return of knee extension in our study to baseline at 6 minutes is similar to the inability of the hip joint in Bohannon's[17] study to maintain any significant increase 10 minutes after cessation of the stretch. Although the 2 studies differed in procedure, the results suggest that the hamstring complex (including the hip and knee joints) may require greater durations of stretch or increased stretching repetitions in order to create more permanent changes in its contractile and noncontractile components.

The ability of the stretching protocol to increase the angle of knee extension 6.8° (at 1 minute) was slightly less than the 8.0° and 9.2° reported by Worrell et al,[24] and Sullivan et al,[21] respectively. However, our study reported similar results with fewer stretches. All 3 studies incorporated a prebaseline warm-up, used the AKE test to measure knee joint range of motion, and had subjects perform a static stretching protocol in an upright position. The differences in the angle of knee extension at 1 minute recorded by Worrell et al[24] and Sullivan et al[21] may be the result of the number of stretches: 48 total stretches (15 stretching sessions performed over a 3-week period) and 48 total stretches (8 stretching sessions performed over a 2-week period), respectively.

The effect of the repeated AKEs produced a 6.0° increase in the angle of knee extension when comparing the first (129.2° ± 12.3°) with the sixth (135.1° ± 12.4°) extension. This increase in the angle of knee extension may be due to reciprocal inhibition of the hamstrings, resulting in their relaxation and subsequent stretch from the quadriceps contraction used to extend the lower leg.[12] Postbaseline measurements of the control group suggest that this knee-extension angle increase was only temporary, which may reflect a temporary increase in sarcomere lengthening[17] and a temporary creep effect.[28,29]

Finally, the control group had decreased knee extension 6 minutes after the baseline measure (3-minute measurement interval plus 3 minutes of lying quietly) and continued to decline through the 30-minute measure. This phenomenon also occurred in the stretch group. The Table reveals that the knee extension had decreased to baseline 6 minutes poststretching and continued to decrease. We speculate that, had the measurements continued beyond 30 minutes, the stretch group's knee extension also would have decreased below baseline. The exact reason for this is not known. However, it may represent an increase in muscle viscosity produced during the quiet lying. Most likely, if muscle viscosity had increased, it was due to a decrease in muscle temperature. We placed no restrictions on a subject's activity before beginning data collection, nor did we wait a specified time before taking measures. Thus, it is likely that the muscle was in a relatively warm state at the beginning of data collection and cooled as the experiment progressed.

CONCLUSIONS

Our results suggest that 6 repeated active knee extensions before stretching are sufficient to increase knee joint angle and that a protocol of 4 30-second static stretches can further increase this angle. However, these range-of-motion gains are only temporary and short in duration. Athletes who statically stretch and then wait longer than 3 minutes before entering a game or practice can expect to lose the range of motion gained. Future research should determine whether intermittent stretching or activity alone is sufficient to maintain temporary increases in range of motion obtained from acute stretching bouts. Research determining the most efficient type of acute stretching to effect same-day range-of-motion increases is warranted, as is investigation to determine the optimal duration of stretch to produce long-term or permanent changes. Finally, comparisons between men and women, across age groups, and between subjects with range restriction ≥20° and <20° should be performed to determine whether these findings generalize beyond young men with a 20° or greater restriction.

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