Duration of Maintained Hamstring Flexibility After a One-Time, Modified Hold-Relax Stretching Protocol

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Objective: Previous research suggests proprioceptive neuromuscular facilitation (PNF) stretching techniques produce greater increases in range of motion than passive, ballistic, or static stretching methods. The purpose of our study was to measure the duration of maintained hamstring flexibility after a 1-time, modified hold-relax stretching protocol.

Design and Setting: The study had a 1×1 mixed-model, repeated-measures design. The independent variables were group (control and experimental) and time (0, 2, 4, 6, 8, 16, and 32 minutes). The dependent variable was hamstring flexibility as measured in degrees of active knee extension with the hip flexed to 90°. Measurements were taken in a preparatory military academy athletic training room.

Subjects: Thirty male subjects (age, 18.8 ± 0.63 years; height, 185.2 ± 14.2 cm; weight, 106.8 ± 15.7 kg) with limited hamstring flexibility in the right lower extremity were randomly assigned to a control (no-stretch) group or an experimental (stretch) group.

Measurements: All subjects performed 6 warm-up active knee extensions, with the last repetition serving as the pre-stretch measurement. The experimental group received 5 modified (no-rotation) hold-relax stretches, whereas the control group rested quietly supine on a table for 5 minutes. Posttest measurements were recorded for both groups at 0, 2, 4, 6, 8, 16, and 32 minutes.

Results: The repeated-measures analysis of variance revealed a significant group-by-time interaction, a significant main effect for group, and a significant main effect for time. Dunnett post hoc analysis revealed a significant improvement in knee-extension range of motion in the experimental group that lasted 6 minutes after the stretching protocol ended.

Conclusions: Our findings suggest that a sequence of 5 modified hold-relax stretches produced significantly increased hamstring flexibility that lasted 6 minutes after the stretching protocol ended.

Key Words: active knee-extension test, knee joint range of motion

Flexibility is a key component for injury prevention and rehabilitation. Stretching is important for reducing injury and improving performance in sports and for overall physical fitness. Athletes are often given stretching protocols to improve their flexibility. Several stretching techniques are used to increase joint range of motion (ROM).2–12

A number of previous studies have demonstrated that proprioceptive neuromuscular facilitation (PNF) stretching techniques produce greater increases in ROM than passive, static, or ballistic stretching methods.2,4–13 However, other studies have reported that the results achieved with static and ballistic stretching techniques are comparable with those achieved with PNF stretching techniques.14–16

Regardless of the techniques used, flexibility gains in the hamstring muscles have been demonstrated after a multiple-day stretching program.13,16,17 These studies have shown that frequency and duration of static, ballistic, and PNF stretches affect ROM gains. However, the duration of flexibility gains after a single stretching session has received limited study. A 1-time session of 4 consecutive 30-second static stretches has been shown to increase flexibility for 3 minutes after the stretching protocol.18 Previous research has not focused on the duration of flexibility gains after a single, same-day series of hold-relax stretches. Thus, the purpose of our study was to measure the duration of hamstring flexibility gains after a 1-time hold-relax stretching protocol.

METHODS

Subjects

We recruited 30 healthy male military cadets (age, 18.8 ± 0.63 years; height, 185.2 ± 14.2 cm; weight, 106.8 ± 15.7 kg) to participate in this study. All subjects read and signed an informed consent form approved by the University of Vir-
ginia Committee for the Protection of Human Subjects, which also approved the study.

Preparticipation Screening
Subjects were included in the study if they had visible evidence of hamstring tightness, defined as a limitation of 20° or more from full extension as determined by the active knee-extension (AKE) test, and were injury free in the trunk and lower extremities for at least 6 months before the study.18

Subject Positioning for AKE Testing
With subjects lying on their left sides, the greater trochanter of the right femur, lateral femoral epicondyle, and lateral malleolus of right fibula were identified and marked with a black felt-tip marker to help ensure proper alignment for goniometric measurements. Subjects were positioned supine on an examination table with the hip flexed to 90° as measured by a goniometer (Rolyan Medical Products, Menomonee Falls, WI). A polyvinylchloride pipe frame served as a cross-bar so that 90° hip flexion was maintained throughout AKE measurements. The investigator ensured that the distal anterior thigh maintained contact with the cross-bar for all AKE measurements (Figure 1). Throughout the AKE procedure, the left hip remained at 0° of flexion.19 A gravity-assisted protractor (Empire Level Manufacturing Co, Mukwonago, WI) was attached 2.54 cm below the right fibular head by a hook-and-loop strap. The protractor was adjusted to read 90° when the knee was flexed to 90°. The investigator recorded protractor measurements of AKE on the right side.

Testing Procedure

Prestretch Measurement. For prestretch measurements, subjects in both groups performed a total of 6 AKEs with a 60-second rest period between repetitions. The first 5 AKEs served as warm-ups to decrease any effect that may occur with repeated measures performed from a cold start.18 The sixth AKE was recorded as the prestretch measurement. When the subject could not extend his lower leg any farther without his thigh moving away from the cross-bar, he informed the investigator and held that position for approximately 2 to 3 seconds until a measurement was taken. This method of measuring hamstring flexibility was found to be reliable (intraclass correlation coefficient [2,1], 0.96; standard error of measurement, ±2.29°).18

Poststretch Measurement. Poststretch measurements were performed in the same manner as the prestretch measurements, except that no warm-up contractions were performed. One AKE measurement was taken at 0 minutes (immediately) and at 2, 4, 6, 8, 16, and 32 minutes after the final stretch in the experimental group. The control group underwent the same poststretch measurement protocol immediately after 5 minutes of lying quietly on the table. Measurements of the angle of knee joint ROM were recorded.

Stretching Protocol
Subjects were randomly assigned to either the control or the stretching group. The 15 subjects assigned to the stretching group received visual and verbal instruction in performing the modified hold-relax stretch.4,20 This modified hold-relax stretch was performed with no hip rotation. Predetermined time intervals for stretching, contracting, and relaxing were used to standardize stretching methods for the stretching group. For each stretch, the investigator passively stretched the hamstrings until the subject first reported a mild stretch sensation and held that position for 7 seconds. Next, the subject maximally isometrically contracted the hamstrings for 7 seconds by attempting to push his leg back toward the table against the resistance of the investigator (Figure 2). After the contraction, the subject relaxed for 5 seconds. The investigator then passively stretched the muscle until a mild stretch sensation was reported. The stretch was held for another 7 seconds. This sequence was repeated 5 times on each subject in the experimental group. All stretching was performed on the right lower extremity. The 15 subjects assigned to the control group lay supine on the evaluation table for 5 minutes, the approximate time it took to stretch the experimental group.

Statistical Analysis
A mixed-model, 1 between (group) by 1 within (time), repeated-measures analysis of variance was used to determine
Viscoelastic Properties

Musculotendinous units function in a viscoelastic manner, and, therefore, have the properties of creep and stress relaxation. Creep is characterized by the lengthening of muscle tissue due to an applied fixed load. Stress relaxation is characterized by the decrease in force over time necessary to hold a tissue at a particular length. The musculotendinous unit deforms or lengthens as it is being stretched and goes through elastic and then plastic deformation before completely rupturing. Our results suggest that a single session of hold-relax stretching does not deform tissues enough to produce a permanent change (ie, a plastic deformation in the musculotendinous unit). Therefore, the temporary improvement in hamstring flexibility may be attributed to changes in the elastic region caused by a single session of hold-relax stretching.

This temporary benefit of increasing hamstring flexibility has been previously reported. Tanigawa demonstrated a significant increase in hamstring flexibility for PNF and static stretching groups relative to a control group. However, he reported a decrease in hamstring flexibility in both static and PNF stretching groups 2 days after the 4-week stretching program. Tanigawa concluded that the maintenance of increased flexibility requires a regular routine of stretching. Tanigawa’s study and our study support the position that stretching programs produce elastic deformations that allow the tissue to return to its original length if the stretching routine is not continued.

Thixotropic Properties

Because of the controlled nature of this study, we asked subjects to lie still on a table between poststretch measurements. This manner of control presented an interesting response. We found a significant decrease in hamstring flexibility in the control group after 2 minutes of inactivity. Additionally, a return toward baseline flexibility was noted after the 6-minute poststretch measurement.

One explanation for this occurrence is the thixotropic properties of the muscle. Thixotropy is the property of a tissue to become more liquid after motion and return to a stiffer, gel-like state at rest. The thixotropic property of muscle is thought to result from an increase in the number of stable bonds between actin and myosin filaments when the muscle is at rest. Hence, the stiffness of muscle increases.

Because we asked our subjects to lie still, the thixotropic properties of muscle may have played a part in reducing the time that hamstring flexibility was increased. A linear relationship exists between the time a muscle remains still and the stiffness of that muscle in response to a stretch, and indeed, flexibility decreased in both groups as time passed (Table). However, with activity, the muscle becomes more fluid-like.
because the stable bonds are broken or are prevented from forming.27,28

We believe that it should be noted that these laboratory conditions are not representative of field situations. Thus, based on thixotropic properties, we would expect the temporary increase in flexibility to be maintained during periods of activity and to decrease during periods of inactivity.

**Neural Properties**

Even though we made no neurologic assessments during this study, studies of similar PNF stretching techniques suggest that autogenic inhibition of the stretched muscle provides increased ROM.3,4,29,30 Autogenic inhibition was defined by Knott and Voss3 as the inhibition of the homonymous muscle alpha motor neurons by the stimulation of the Golgi tendon organ. This inhibitory effect is thought to diminish muscle activity and, therefore, allow for relaxation so that the muscle can be stretched. Motor pool excitability has been measured by the Hoffman reflex during soleus muscle static stretching, contract-relax stretching, and contract-relax–agonist-contrast stretching techniques. Motor pool excitability significantly diminished after the contract-relax and contract-relax– antagonist-contrast methods of PNF stretching over static stretching of the soleus.30 This inhibitory effect has been suggested to increase muscle compliance, allowing for increased length during a stretch without stimulation of the stretch reflex.30

Increased sensitivity of primary and secondary musculotendinous afferent receptors, termed postcontraction sensory discharge, after a muscular contraction has been demonstrated.31 This effect would potentially increase muscle spindle sensitivity to stretch. However, this increased sensitivity is disrupted when the muscle is stretched beyond the length of the contraction.31

The neurologic contribution associated with the various PNF stretching techniques is somewhat contradictory.32,33 The ROM gains demonstrated in this study were temporary, a finding supported by the temporary inhibition of the motor pool with the contract-relax PNF stretching technique.30 The temporary response seen in this modified hold-relax stretching technique is most likely due to the combination of these factors.

**Future Research**

Future research should address a single stretching routine followed immediately by activity to enhance the lasting effect of the stretching routine. These routines should study different populations, such as women and older adults, since only healthy young men were evaluated in this study, and the results of a single stretching session may be quite different in these other populations. The duration of maintaining a stretched muscle of different architecture also needs further study. Also, the most effective PNF technique for same-day ROM gains warrants further research.

**CONCLUSIONS**

A 1-time, modified hold-relax stretching protocol was effective in increasing hamstring flexibility as measured by AKE. However, the gains in ROM lasted for only 6 minutes after the final stretch, and this protocol may not be any more effective than static stretching. These findings may have clinical implications in terms of how often a stretching routine should be performed in a day to maintain flexibility gains, especially if a person will be primarily sedentary.

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**REFERENCES**


