Journal of Athletic Training 2001;36(1):44–48
© by the National Athletic Trainers' Association, Inc
www.journalofathletictraining.org

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

Scott G. Spernoga*; Timothy L. Uhl†; Brent L. Arnold‡; Bruce M. Gansneder‡

*Wake Forest University, Winston-Salem, NC; †University of Kentucky, Lexington, KY; ‡University of Virginia, Charlottesville, VA

Scott G. Spernoga, MS, ATC, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting and final approval of the article. Timothy L. Uhl, PhD, ATC, PT, Brent L. Arnold, PhD, ATC, and Bruce M. Gansneder, PhD, contributed to conception and design; analysis and interpretation of the data; and drafting, critical revision, and final approval of the article.

Address correspondence to Timothy L. Uhl, PhD, ATC, PT, CAHP Building, Room 205, 121 Washington Avenue, Lexington, KY 40536-0003. Address e-mail to tluhl2@pop.uky.edu.

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 prestretch 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.[1] 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-

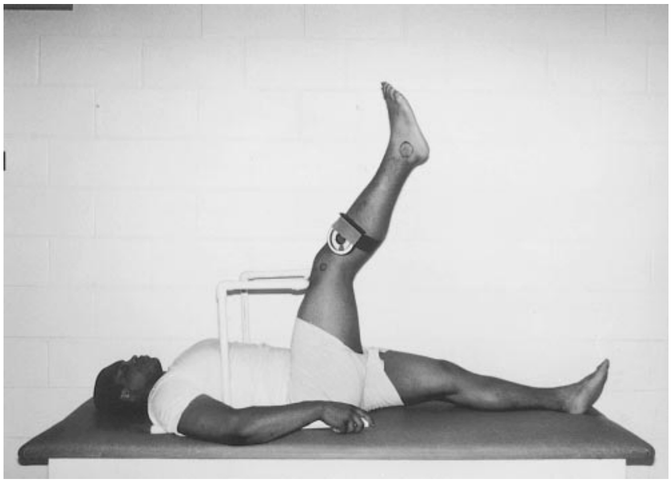

Figure 1. Subject positioned under the polyvinylchloride pipe frame and performing active knee extension to measure hamstring flexibility.

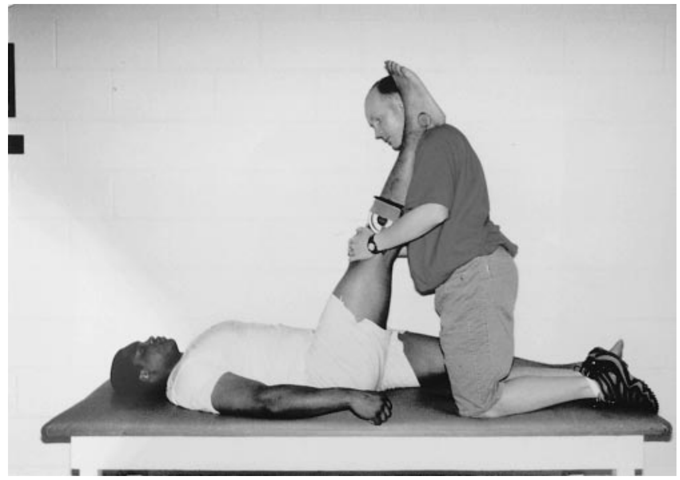

Figure 2. Subject performing isometric contraction of hamstring against resistance of the investigator.

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

Active Knee-Extension Measurements*

Time (min)	Group	
	Control	Experimental
Prestretch	40.53 ± 10.97	38.80 ± 11.18
0	42.87 ± 11.28	31.00 ± 9.20†
2	43.33 ± 11.42†	32.23 ± 8.53†
4	44.67 ± 11.48†	34.47 ± 8.66†
6	45.40 ± 11.69†	36.27 ± 9.45†
8	46.60 ± 11.82†	37.20 ± 9.28
16	48.10 ± 12.40†	39.10 ± 10.24
32	49.47 ± 13.12†	40.60 ± 11.36

*Values are expressed as mean ± SD degrees.
†Significantly different from prestretch ($P < .05$).

differences for knee-extension angles between groups and across time. Dunnett post hoc analysis was used to compare each group's poststretch measurement with the same group's prestretch measurement.[21]

RESULTS

A repeated-measures analysis of variance revealed a significant group-by-time interaction ($F_{7,239} = 14.97$, $P < .01$), a significant main effect for group ($F_{1,239} = 5.25$, $P = .03$), and a significant main effect for time ($F_{7,239} = 47.86$, $P < .01$). Dunnett post hoc analysis revealed that a significant ($P < .05$) increase in hamstring flexibility was maintained in the experimental group for 6 minutes after the stretching protocol (Table). Post hoc analysis demonstrated a significant ($P < .05$) decrease in flexibility in the control group starting at 2 minutes.

DISCUSSION

This study demonstrated that hamstring flexibility remains significantly increased after the modified hold-relax stretching protocol for 6 minutes. In a previous study using a static stretching protocol, hamstring flexibility increased significantly but only remained increased for 3 minutes after stretching.[18]

The literature is inconclusive regarding which stretching method is best for increasing muscle length. Previous studies support greater increases in ROM with PNF stretching techniques than with passive, static, or ballistic stretching methods.[2,4–13] However, some studies[14,15] suggest no difference between PNF and other stretching techniques. Several methodologic differences in the studies and the statistical manipulation of the data confound this issue.

One example is the statistical analysis methods used in this study and the study of DePino et al.[18] We employed a Dunnett post hoc analysis to compare each poststretch measurement with the same prestretch measurement. In contrast, DePino et al[18] used the less powerful Tukey post hoc analysis to determine significant differences among the poststretch measurements. Because the 2 studies differed at the 6-minute time point, we calculated the effect size at the 6-minute time point to compare the studies. The effect size was calculated by the equation (prestretch mean − 6-minute poststretch mean)/SD prestretch. This calculation produced effect sizes of 0.24 and 0.22 in the study of DePino et al[18] and in our study, respectively. The effect sizes between the 2 methods of stretching are similar, indicating that the improvement in hamstring flexibility was increased proportionally for both techniques. DePino et al might have found significant differences later than 3 minutes if Dunnett analysis had been performed. Therefore, the differences reported in these 2 studies may be due to statistical, rather than actual, differences between the 2 stretching techniques.

The relatively short time of increased hamstring flexibility may be due to several factors. The most prominent are the viscoelastic, thixotropic, and neural properties of the musculotendinous unit.

Viscoelastic Properties

Musculotendinous units function in a viscoelastic manner, and, therefore, have the properties of creep and stress relaxation.[22,23] Creep is characterized by the lengthening of muscle tissue due to an applied fixed load.[22] Stress relaxation is characterized by the decrease in force over time necessary to hold a tissue at a particular length.[22] The musculotendinous unit deforms or lengthens as it is being stretched and goes through elastic and then plastic deformation before completely rupturing.[24] 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[4] 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[4] 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.[25,26] 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,[26] 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 Voss[3] 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-contract stretching techniques. Motor pool excitability significantly diminished after the contract-relax and contract-relax–antagonist-contract 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.

ACKNOWLEDGMENTS

We thank Bill Webright, MEd, PT, ATC, for the use of the apparatus to perform this study.

REFERENCES

1. Corbin CB, Noble L. Flexibility: a major component of physical fitness. *J Phys Educ Recreat Dance.* 1980;51:57–60.
2. Prentice WE. A comparison of static stretching and PNF stretching for improving hip joint flexibility. *J Athl Train.* 1983;18:56–59.
3. Knott M, Voss DE. *Proprioceptive Neuromuscular Facilitation: Patterns and Techniques.* 2nd ed. Philadelphia, PA: Harper and Row; 1968.
4. Tanigawa MC. Comparison of the hold-relax procedure and passive mobilization on increasing muscle length. *Phys Ther.* 1972;52:725–735.
5. Wallin D, Ekblom B, Grahn R, Nordenborg T. Improvement of muscle flexibility: a comparison between two techniques. *Am J Sports Med.* 1985;13:263–268.
6. Hardy L, Jones D. Dynamic flexibility and proprioceptive neuromuscular facilitation. *Res Q.* 1986;57:150–153.
7. Cornelius WL, Hinson MM. The relationship between isometric contractions of hip extensors and subsequent flexibility in males. *J Sports Med Phys Fitness.* 1980;20:75–80.
8. Etnyre BR, Abraham LD. Gains in range of ankle dorsiflexion using three popular stretching techniques. *Am J Phys Med.* 1986;65:189–196.
9. Holt LE, Travis TM, Okita T. Comparative study of three stretching techniques. *Percept Mot Skills.* 1970;31:611–616.
10. Sady SP, Wortman M, Blanke D. Flexibility training: ballistic, static, or proprioceptive neuromuscular facilitation? *Arch Phys Med Rehabil.* 1982;63:261–263.
11. Etnyre BR, Lee EJ. Chronic and acute flexibility of men and women using three different stretching techniques. *Res Q.* 1988;59:222–228.
12. Osternig LR, Robertson RN, Troxel RK, Hansen P. Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch techniques. *Med Sci Sports Exerc.* 1990;22:106–111.
13. Hardy L. Improving active range of hip flexion. *Res Q.* 1985;56:111–114.
14. Worrell TW, Smith TL, Winegardner J. Effect of hamstring stretching on hamstring muscle performance. *J Orthop Sports Phys Ther.* 1994;20:154–159.
15. Sullivan MK, Dejulia JJ, Worrell TW. Effect of pelvic position and stretching method on hamstring muscle flexibility. *Med Sci Sports Exerc.* 1992;24:1383–1389.
16. Hardy L, Jones D. Dynamic flexibility and proprioceptive neuromuscular facilitation. *Res Q.* 1986;57:150–153.
17. Bandy WD, Irion JM, Briggler M. The effect of time and frequency of static stretching on flexibility of the hamstring muscles. *Phys Ther.* 1997;77:1090–1096.
18. DePino GM, Webright WG, Arnold BL. Duration of maintained hamstring flexibility following cessation of an acute static stretching protocol. *J Athl Train.* 2000;35:56–59.
19. Cameron DM, Bohannon RW. Relationship between active knee extension and active straight leg raise test measurements. *J Orthop Sports Phys Ther.* 1993;17:257–260.
20. Markos PD. Ipsilateral and contralateral effects of proprioceptive neuromuscular facilitation techniques on hip motion with electromyography activity. *Phys Ther.* 1979;59:1366–1373.
21. Glass GV, Hopkins KD. *Statistical Methods in Education and Psychology.* 3rd ed. Boston, MA: Allyn and Bacon; 1996.
22. Taylor DC, Dalton JD Jr, Seaber AV, Garrett WE Jr. Viscoelastic properties of muscle-tendon units: the biochemical effects of stretching. *Am J Sports Med.* 1990;18:300–309.
23. Stromberg DD, Wiederhielm CA. Viscoelastic description of a collagenous tissue in simple elongation. *J Appl Physiol.* 1969;26:857–862.
24. Nikolaou PK, Macdonald BL, Glisson RR, Seaber AV, Garrett WE Jr.

Biomechanical and histological evaluation of muscle after controlled strain injury. *Am J Sports Med.* 1987;15:9–14.
25. Walsh EG. Postural thixotropy: a significant factor in the stiffness of paralysed limbs? *Paraplegia.* 1992;30:113–115.
26. Lakie M, Robson LG. Thixotropic changes in human muscle stiffness and the effects of fatigue. *Q J Exp Physiol.* 1988;73:487–500.
27. Lakie M, Walsh EG, Wright GW. Resonance at the wrist demonstrated by the use of a torque motor: an instrumental analysis of muscle tone in man. *J Physiol.* 1984;353:265–285.
28. Hagbarth KE, Hagglund JV, Nordin M, Wallin EU. Thixotropic behaviour of human finger flexor muscles with accompanying changes in spindle and reflex responses to stretch. *J Physiol.* 1985;368:323–342.
29. Jami L. Golgi tendon organs in mammalian skeletal muscle: functional properties and central actions. *Physiol Rev.* 1992;72:623–666.
30. Etnyre BR, Abraham LD. H-reflex changes during static stretching and two variations of proprioceptive neuromuscular facilitation techniques. *Electroencephalogr Clin Neurophysiol.* 1986;63:174–179.
31. Smith JL, Hutton RS, Eldred E. Postcontraction changes in sensitivity of muscle afferents to static and dynamic stretch. *Brain Res.* 1974;78:193–202.
32. Moore MA, Hutton RS. Electromyographic investigation of muscle stretching techniques. *Med Sci Sports Exerc.* 1980;12:322–329.
33. Etnyre BR, Abraham LD. Antagonist muscle activity during stretching: a paradox re-assessed. *Med Sci Sports Exerc.* 1988;20:285–289.