Comparison of Nonballistic Active Knee Extension in Neural Slump Position and Static Stretch Techniques on Hamstring Flexibility

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Abstract:
Nonballistic, active range of motion exercises have been advocated as more effective than static stretching for increasing range of motion, yet no published data exist to support this claim. This study compared the effect of nonballistic, repetitive active knee extension movements performed in a neural slump sitting position with static stretching technique on hamstring flexibility. Forty healthy, adult volunteer subjects with limited right hamstring flexibility (ie., minimum of 15° loss of active knee extension measured with femur held at 90° of hip flexion) were randomly assigned to one of three groups. Group 1 (static stretch) performed a 30-second stretch twice daily. Group 2 (active stretch) performed 30 repetitions of active knee extension while sitting in a neural slump position twice daily. Group 3 served as a control. Hamstring flexibility was determined by an active knee extension test before and after 6 weeks of stretching. Goniometric measurement of knee joint flexion angle was obtained from videotape recording of the active knee extension test. A 3 (group) x 2 (test) repeated measures analysis of variance and subsequent Tukey post hoc testing revealed no significant difference in knee joint range of motion gains between the static (X = 8.9°) and active stretch (X = 10.2º). Both stretch groups' knee joint range of motion improved significantly ($p < .05$) more than the control group. We conclude that 6 weeks of nonballistic, repetitive active knee extensions (30 repetitions, twice daily) performed in a neural slump sitting position improves hamstring flexibility in uninjured subjects, but is no different compared with static stretching (30 seconds, twice daily).

Key Words: neural tension, stretch, active knee extension test, hamstrings

Article:
Various stretching techniques have traditionally been used in an attempt to improve hamstring flexibility. Researchers have compared the effectiveness of different techniques to improve hamstring flexibility, including proprioceptive neuromuscular facilitation relaxation techniques (20,29), modifications of proprioceptive neuromuscular facilitation relaxation techniques (7,11-13,15,22,24,25,27,33), ballistic stretching (12,15,25), and static stretching (7,11-13.15,22,24,25, 27,29,33), Use of nonballistic, active range of motion exercises has been advocated as more effective than static stretching for increasing range of motion (23), yet no published data exist to support this view.

Gajdosik (8) pointed out that along with the hamstrings, the deep fascia of the lower limb and the soft tissues of the pelvis, including neurologic tissue (4,10,31), could limit a straight leg raise test. In the same way, these noncontractile tissues can come under tension during passive or active movements of hip flexion or knee extension. If tension of noncontractile tissue limits indirect measures of hamstring flexibility, ie., straight leg raise or active knee extension tests, then use of a stretching technique that emphasizes these tissues, along with the hamstrings, may be justified.

Maitland (16-18) described a neural tension test (ie., slump test) in which active knee extension is performed by subjects in a sitting position while maintaining cervical and thoracolumbar flexion. This position effectively tensions the Jura, spinal cord, and lumbosacral nerve roots. (3) A normal response of limited knee extension and ankle dorsiflexion range of motion occurred in the flexed, or slumped posture, but full range was achieved after cervical flexion was released and the head returned to the upright position (16,17). Rather than shortened hamstrings, Maitland (16) implicated the loss of movement of the dura mater and nerve root sleeves within the vertebral canal as the cause of limited knee extension and ankle dorsiflexion range of motion during the slump maneuver. Maitland (16-19) and Butler (5) describe in detail the slump test sequence and its clinical application in assessment and treatment of spinal dysfunction. Use of active knee extension movement in a neural slump test posture would appear to effectively tension neural and hamstring tissues.

Group	Age (years)		Height (cm)		Weight (kg)		Gender
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	
SS	21.2	3.65	172.6	10.99	64.6	10.73	6M, 9F
AS	20.8	3.16	171.2	7.27	62.7	7.91	6M, 5F
Control	22.1	2.50	174.4	8.51	71.9	11.69	10M, 4F

SS = Static stretch.
AS = Nonballistic active stretch.
M = Males.
F = Females.

TABLE 1. *Description of groups ($\bar{X} \pm SD$).*

The purpose of this study was to determine the effectiveness of non-ballistic, repetitive active knee extension movements performed in a neural slump sitting position on hamstring flexibility in uninjured subjects. A static stretch group and control group were used for comparison to the active, nonballistic stretch group. The dependent variable used to assess hamstring flexibility was the angle of knee flexion measured in a supine active knee extension test.

METHODS

Subjects

Forty healthy university graduate and undergraduate male and female students volunteered to participate in the study (18 females, age = 21.3 ± 3.6 years, height = 167.4 ± 8.0 cm, and weight = 59.1 ± 8.0 kg; 22 males, age = 21.5 ± 2.8 years, height = 177.3 ± 7.5 cm, and weight = 72.8 ± 9.0 kg). The age, height, weight, and gender of subjects per group assignment were recorded (Table 1). All subjects were free from injury or disease expected to affect hamstring length or ability to perform the exercises. Subjects qualified for the study by having right hamstring inflexibility, operationally defined by a knee flexion angle greater than 15° as measured by a screening exam using active knee extension in supine with hip flexed 90°. Prior to participation, each subject read and signed an informed consent form that had been approved by a university human subjects research committee.

Instrumentation

A standard, double-armed (arm lengths = 31.75 cm), clear plastic goniometer with full circle protractor (1° increments) was used for the hamstring flexibility screening procedure, hip positioning for the active knee extension test, and knee motion measurements. A plastic-encased bubble level (plastic = 12.7 cm in length; bubble window = 3.8 cm long) was taped parallel to the stationary arm. The bubble level was used to position the hip at 90° of flexion for all active knee extension practice and test trial movements.

A video camera (Sony CCD-F501, Sony Electronics, Inc., Park Ridge, NJ) was used to record the position of the lower extremity during the active knee extension test. A video cassette recorder (JVC model HRVP606U;

JVC Company of America, Elmwood Park, NJ) with jog/shuttle control allowing frame by frame advancement was used for tape replay. The cassette recorder was relayed to a television (JVC model C-13560) with a 33.0-cm monitor screen. The monitor screen was overlaid with a clear, flat plastic cover, 26.0 cm x 34.3 cm, which allowed for placement of the standard goniometer for measurement of knee joint motion.

Procedure

Screening exam. The screening exam was used to determine subject eligibility in the study. Subjects were placed supine with the left lower extremity in 0° of hip flexion. Subjects stabilized the right hip at 90° of flexion by interlocking the fingers of both hands at the distal thigh. Subjects were instructed to actively extend their right knee to its limit, keeping the foot relaxed in plantar flexion. The goniometer was used to measure the degrees from full (0°) extension. Subjects demonstrating a knee flexion angle greater than 15° were operationally defined as having hamstring inflexibility and allowed to participate in the study.

Active knee extension test. Adhesive tape was applied to the right lower extremity of each subject in left side-lying at the following landmarks: 5.0 cm distal to the greater trochanter, 5.0 cm proximal to the lateral femoral epicondyle, 5.0 cm distal to the fibular head, and 5.0 cm proximal to the inferior lip of the lateral malleolus. Subjects were positioned supine on an unpadded plywood sheet under a polyvinylchloride pipe apparatus. The cross bar of the apparatus helped each subject maintain hip flexion at 90° during the active knee extension movement. Prior to each trial movement, the goniometer was used to reposition the hip at 90° of flexion. The left lower extremity rested at 0° of hip flexion. A rolled towel was placed under the head and neck to support the cervical spine.

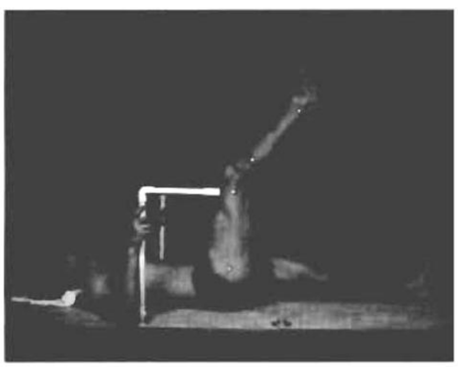

FIGURE 1. *Active knee extension test.*

Each subject performed four practice trials and three test trials of active knee extension with the ankle in relaxed plantar flexion (Figure 1). The practice trials provided a warm-up period to decrease the potential for increases in the angle of knee extension that might result from measuring repeated trials from a cold start (1). An audio cassette recording aided the subject in completing each trial in approximately 4 seconds, with the end range knee extension position attained during the last second. A 60-second rest period was used between each trial movement. After each trial, subjects rested the test extremity by moving into hip and knee flexion angles that allowed foot flat placement.

Film was collected on the three active knee extension test trials. The video camera was mounted on a tripod at a height of 119.4 cm from the floor to the bottom of the camera lens, approximating alignment with each subject's knee joint. The front of the lens was 2.86 m from the edge of the plywood sheet. A plastic-encased bubble level (plastic = 12.7 cm in length; bubble window = 3.8 cm long) placed on top of the camera's viewfinder allowed camera tilt to be leveled parallel.

Our active knee extension test was a modification of that used by Gajdosik and Lusin (9). Similarities between the two test methods included goniometric positioning of the hip in 90° of flexion, maintaining continuous thigh contact with the cross bar, and keeping the foot in relaxed plantar flexion during the test movement. In contrast, Gajdosik and Lusin (9) recorded the knee flexion angle after subjects were instructed to slightly flex their knee to stop the myoclonus induced by the knee extension effort. We avoided inducing visible myoclonus as our subjects paused 1 second at their end range of knee extension movement. Measurement methods differed as we recorded knee flexion angles from video, while Gajdosik and Lusin (9) used a pendulum goniometer placed directly on their subjects' lower leg. We did not use stabilizing straps at either the pelvis or contralateral extremity as did Gajdosik and Lusin (9).

Reliability
Prior to the experimental study, a pilot study was conducted to determine the intratester and intertester reliability of the active knee extension test. Using the procedures described in the methods section, 12 subjects were tested on two different days, 1-3 days apart. The mean of the three measurement trials obtained during the two measurement sessions was used for both intratester and intertester reliability [ICC (2,1)] as described by Shrout and Fleiss (26). The standard error of measurement (SEM) as described by Denegar and Ball (6) was used to provide an estimate of measurement precision. To minimize diurnal effects between measures, each subject was measured on the second test session day within 30 minutes of the first test session time. Results revealed that the intratester ICC and SEM for tester one (BJR) was 0.98 and 1.68°; intratester ICC and SEM for tester two (WGW) was 0.98 and 1.70°; and intertester ICC and SEM was 0.98 and 1.67°, respectively.

Group Assignment and Instruction
Following pretreatment assessment of hamstring flexibility using the active knee extension test, subjects were randomly assigned to one of three groups: *1*) Group 1 performed static hamstring stretching for 30 seconds twice daily; *2*) Group 2 performed 30 active knee extension repetitions while maintaining ankle dorsiflexion in sitting neural slump posture twice daily; and *3*) Group 3, which served as the control group, received no stretching instruction. After 6 weeks of unsupervised stretching, hamstring flexibility was reassessed using the active knee extension test. To control for the effect of diurnal changes in active knee extension ROM, posttests of each subject were performed within 30 to 60 minutes of their pretest session time.

Each subject was informed of random group assignment and given instruction by the investigator. Control group subjects were asked to maintain their normal pattern of physical activity for the duration of the study. Subjects assigned to either stretch group watched a video that provided demonstration and verbal instruction of the stretching technique. All stretch group subjects performed the stretch to the right lower extremity and received corrective feedback from the investigator. Each stretch group subject received a written description with a drawing of the stretch.

Static hamstring stretch. The static hamstring stretch was performed on the floor in a modified hurdler's position (Figure 2). Subjects flexed forward from the hips, attempting to maintain the spine in a neutral position. It was emphasized to each subject to try and maintain the neutral spine by avoiding cervical flexion and moving only from the hips. Subjects flexed from the hip until a stretch sensation was felt in the posterior thigh, knee, and/or calf. Once this position was achieved, the stretch was sustained for 30 seconds. Use of the 30-second stretch duration was based on the work of Bandy and Irion (2), who reported this duration as more effective than 15 seconds, and equal in effectiveness to 60 seconds, for increasing hamstring flexibility. Each subject used a verbal self-count from "one one-thousand" to "thirty one-thousand" to approximate the 30-second stretch duration.

Non ballistic active stretch. The nonballistic active stretch (Figure 3) was performed sitting on a sturdy object (eg., table, desk top, counter top) at a height which did not allow foot contact with the floor. With the thighs supported, legs flexed, and popliteal fossae touching the table edge, the subject sat slumped as far as possible, producing full thoracolumbar flexion. The cervical spine was then fully flexed. With fingers interlocked, the subject's hands were placed on the posterior aspect of their head. Overpressure was provided to the cervical and thoracolumbar spines by the weight of the relaxed arms. The right foot was maximally dorsiflexed. The knee was then extended to end range while dorsiflexion was maintained, End range of knee extension was operationally defined as the point where firm resistance or stretch was felt at the posterior thigh, knee, and/or calf. This end range knee extension stretch position was held for a verbal self count of "one one-thousand." The subject then lowered the leg and relaxed the foot in plantar flexion. This stretch movement sequence was repeated rhythmically for a total of 30 repetitions. The sitting slump posture was maintained by overpressure throughout the total repetitions.

FIGURE 2. *Static hamstring stretch.*

FIGURE 3. *End position for the nonballistic active knee extension stretch in neural slump sit position.*

With each active knee extension repetition maintained at end range approximately I second, the total time spent at end range in the neural slump sitting position would approximate the 30 seconds of the static stretch group. By attempting to equalize the time spent at end range for both stretch groups, we felt that the 30 active repetitions would emphasize the movement component of the active stretch group compared with the static stretch group. Additionally, by equalizing the total time spent at end range for both groups, any differences in ROM gains following treatment might he due to body positions and their effect on the different tissues that limit joint movement.

Data Reduction and Analysis

All knee measurements were taken directly from the videotape as projected on the television monitor screen. The universal goniometer was placed directly on the clear, Hat plastic covering which overlaid the television monitor screen. Angle of knee flexion was determined by measuring the angle between the intersecting lines of the thigh (tape marks 5.0 cm distal to the greater trochanter and 5.0 cm proximal to the lateral femoral epicondyle) and leg (tape marks 5.0 cm proximal to the fibular head and 5.0 cm proximal to the inferior lip of the lateral malleolus).

A 3 (group) X 2 (test) repeated measures analysis of variance was used to examine pretest to posttest differences and group differences in knee flexion angles. Probability was set at $p < .05$. Tukey HSD post hoc analysis was computed to determine where significant differences occurred among the groups.

RESULTS

Means and standard deviations for the active knee extension pretest and posttest values for each experimental group are presented in Table 2. The means represent degrees from complete active knee extension with the hip maintained at 90° of flexion. Analysis of variance revealed a significant group by test interaction ($F = 11.89$, $df = 2/37$, $p < 0.001$) (Figure 4). In addition, there was a significant main effect for test ($F = 22.40$, $df = 1/37$, $p < 0.001$). A subsequent Tukey HSD post hoc analysis revealed that both the static and active stretch groups' knee joint range of motion improved significantly more than the control group pre- to posttest ($p < .05$). No significant difference in pre- to posttest measures of knee joint range of motion occurred between the static and active stretch groups.

The total possible stretch sessions for each subject equaled 84 during the 6-week period. The means and standard deviations for stretch sessions were static stretch group = 75.8 ± 5.7 and modified neural slump stretch group = 74.8 ± 7.8. Subjects verbally reported the number of missed sessions, from which the total sessions performed was determined.

Group	N	Pretest			Posttest			Difference
		$\bar{X}$	SD	Range	$\bar{X}$	SD	Range	
SS	15	35.1°	9.7	21.3–54.3	26.2°	9.2	12.0–42.3	8.9°
AS	11	34.0°	7.7	23.7–50.7	23.8°	10.4	5.3–43.3	10.2°
Control	14	31.4°	6.6	19.0–40.7	33.9°	6.9	22.0–44.7	−2.5°

SS = Static stretch.
AS = Nonballistic active stretch.
Changes in knee joint range of motion as measured by the active knee extension test. Smaller values on the posttest indicate greater knee extension, ie., increased hamstring flexibility.

TABLE 2. *Knee flexion angles.*

DISCUSSION

This study of uninjured subjects found no significant difference between static stretching and nonballistic, repetitive active knee extensions performed in the sitting neural slump position. The static stretch and active stretch groups increased active knee extension values 8.9° and 10.2°, respectively. The increase in range of motion for the static stretch group is in agreement with studies using the active knee extension test as a measure of hamstring flexibility (27,33). Worrell et al (33) reported an 8.0° increase for static stretching after 15 stretching sessions. Sullivan et al (27) reported a 9.2° increase for static stretching after 10 stretching sessions. The number of reported static stretch sessions (X ± SD) in our study (75.8 ± 5.7) appears excessive when the subsequent range of motion gain is similar to the 15 and 10 stretch sessions of Worrell et al (33) and Sullivan et al (27), respectively.

Prior to initiating nonballistic knee extension, our active stretch group subjects dorsiflexed their ankles and maintained a full spinal slump posture, including cervical flexion. This was done with the thought that if active knee extension range of motion is limited in a full spine neural slump posture (16,17), then the neural tissues placed on tension by this positioning would limit knee extension along with hamstring contractile tissue. A limitation of this study was the inability to identify the specific tissues mobilized by either stretch group. Future research comparing knee angles, using the supine active knee extension test and sitting neural slump test, may help implicate tissue sensitivity to different stretching techniques.

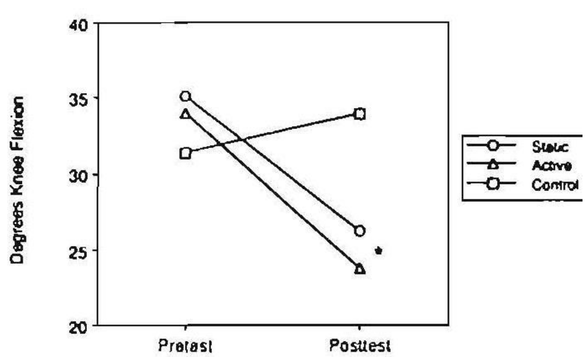

FIGURE 4. *Group × test interaction for active kne extension. * indicates the active and static stretc groups' range of motion is significantly greater tha the control group's (p < .05).*

The improved range of motion gains demonstrated by both stretch groups may be indicative of viscoelastic (21,30) and lengthening changes (8,28,32) of the hamstrings. Using an *in vivo* animal stretch model, Taylor et al (30) demonstrated sustained musculotendinous unit elongation due to stress relaxation and creep in simulated static stretching and cyclic stretching, respectively. McHugh et al (21) provided further support for viscoelastic stress relaxation using a human static stretch model which produced hamstring elongation from straight leg raise stretching. In contrast to acute stretching bouts, Gajdosik (8) reported increased hamstring length and resistance to passive stretch following 3 weeks of daily static stretching. Generalizing animal studies of muscle immobilized in lengthened positions allow for possible explanations of these human hamstring length and resistance ad aptations. Animal muscle immobilized in lengthened positions demonstrated an increased number of sarcomeres (28,32) and a shift in the passive length-tension curve (28,32), indicating increased muscle extensibility compared with muscle immobilized in a shortened position.

The cyclic stretch model of Taylor et al (30) elongated rabbit hind-limb musculature 10% beyond its resting length and was immediately returned to its resting length for 10 repetitions. If our neural slump position prevented full knee extension during the cyclic, nonballistic movements, then it is possible that our subjects were not elongating the hamstrings beyond resting length. While recognizing the difficulty in comparing an animal model with the human model, it remains unclear to the authors how neural tissue and associated skin, fascia, and vasculature affect and contribute to the improved range of motion in our non-ballistic active stretch group.

From the stretching instructions the static and active stretch groups received (ie., video, verbal, and written home instruction) following the active knee extension pretest, we were reasonably confident that the techniques were performed properly. However, a limitation of this study was that stretching was unsupervised. An additional limitation, because the stretching was done unsupervised, was that no physical recording of the number of daily stretch sessions occurred. Instead, the total number of stretch sessions performed was based upon a verbal report of the number of missed sessions at the time of the posttest.

Clinical Implications
This study attempted to look at the potential clinical application of repeated active knee extensions performed in a neural slump posture for improvement of hamstring flexibility in uninjured subjects. The mean improvement of 10.2° could be considered clinically significant. However, based upon the similar flexibility gains of the two stretch groups, the static stretch technique was more time-efficient compared with the active stretch. The duration of one stretch session for the static technique lasted 30 seconds, while the 30 repeated active knee extensions lasted approximately 2 ½ minutes. As such, we recommend the passive stretch because it requires comparatively less time to perform.

The results of our study can be generalized only to an uninjured adult population. Future research should address injured hamstring subjects both with and without signs of adverse neural tissue tension. Of interest would be comparing therapist-applied static neural slump technique (14) with active self-treatment by subjects using repetitive knee extension in the sitting neural slump position. The emphasis of this type of comparative study would be on the return to functional activities, with range of motion gains of secondary, importance. Additionally, research could determine the most effective number of active repetitions needed to increase ROM. Studies such as these will help provide a database to support or reject nonballistic active ROM exercises as an alternative to other treatment or stretching techniques.

CONCLUSIONS
No statistically significant difference in knee joint range of motion gains was seen in this comparative study of uninjured adults in active and static stretch groups. Both stretch groups' knee joint ROM improved significantly ($p < .05$) more than the control group. We conclude that 6 weeks of nonballistic, repetitive active knee extensions (30 repetitions, twice daily) performed in a neural slump sitting position improves hamstring flexibility (determined by a supine active knee extension test), but is no different compared with static stretching (30 seconds, twice daily).

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