

# Effects of Gastrocnemius, Hamstring, and Combined Stretching Programs on Knee Extensibility

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## ■ ABSTRACT

This study examined the effectiveness of hamstrings-only, gastrocnemius-only, and combined hamstrings-gastrocnemius stretching on knee extensibility. The study also compared active knee extension (AKE) test outcomes for two positions: foot relaxed in plantar flexion (AKE-PF) and with ankle fixed in neutral (AKE-N). Forty-seven volunteer participants (94 legs) completed AKE-PF and AKE-N pretests. Forty-five of these participants (89 legs) completed 12 stretching sessions (one 30-second stretch 3 times per week for 4 weeks) and an AKE-PF posttest. Knee extensibility results showed no changes in the control group but similar and significant improvements in all stretching groups, and significant reductions for the AKE-N test compared with the AKE-PF test. Given these findings, clinicians should consider inclusion of gastrocnemius stretching in treatment plans designed to improve knee extensibility and monitor foot position during the AKE, perhaps using both plantar and dorsiflexed positions to gather more information regarding the sources of knee inextensibility.

**T**he ability to extend the knee is critical to effective sport participation and functional movements. When movements demand complete knee extension coupled with hip flexion, hamstring flexibility is es-

sential. Athletes, coaches, and sports medicine clinicians widely accept and promote varied stretching routines to improve hamstring flexibility.<sup>1</sup> Many investigations have tried to identify the ideal hamstring stretching routine,<sup>2-17</sup> but findings from a systematic literature review indicate that an ideal routine may not exist.<sup>1</sup> Instead, a variety of stretching techniques (eg, ballistic, proprioceptive neuromuscular facilitation, static), positions (eg, standing, seated, supine), and frequency and duration combinations successfully improve hamstring flexibility.<sup>1</sup> More recent studies<sup>18-20</sup> continue to reinforce these findings, incorporating additional stretching techniques (eg, active controlled) and more varied positions (eg, supported lunge, seated in a chair). Clearly, a variety of effective stretching programs target and improve hamstring flexibility, which increases knee extensibility.

Sports medicine clinicians are typically well versed in the design of stretching programs, and some consider and treat gastrocnemius tautness when trying to improve knee extensibility and treat knee pathology.<sup>21</sup> Human anatomical structure lends support to stretching the gastrocnemius and other posterior knee structures, but there is no known research evidence that demonstrates the effectiveness of gastrocnemius stretching in programs designed to improve knee extensibility. Numerous studies show static hamstring stretching to improve knee extensibility.<sup>2,5-7,12,14,15,22</sup> Given its posterior knee location, perhaps simultaneously stretching both the gastrocnemius and the hamstrings is the most effective way to increase knee extension range of motion.

The primary purpose of this study was to examine the effectiveness of 3 different stretches on knee extensibility during a 4-week program. Of particular interest was the influence of the gastrocnemius. Hamstrings-only and combined hamstrings-gastrocnemius stretching

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protocols were expected to increase knee extensibility as evidence shows increased knee extension with hamstring stretching.<sup>6-8,10-12,15,16,19</sup> The greatest improvements in knee extensibility were expected with the combined hamstrings-gastrocnemius stretch because it targets more of the 2-joint muscles and structures that span the posterior knee. Conversely, the hamstrings-only and gastrocnemius-only stretches were expected to have smaller effects on knee extensibility.

A second goal of this study was to examine the influence of foot position on the active knee extension (AKE) test. The AKE test administration directions state that the ankle should remain relaxed in plantar flexion,<sup>23</sup> yet clinical observations indicate that not all patients maintain this position without feedback. In addition, controlled use of a neutral ankle or dorsiflexed foot position could provide information regarding additional sources of knee inflexibility. In a similar study of hamstring flexibility assessed by the straight leg raise (SLR) test, significant decreases resulted from fixing the foot in 10° of dorsiflexion.<sup>24</sup> There is no known research evidence for the influence of foot position on the AKE test. Thus, the second intent of this study was to determine the influence of a fixed neutral ankle position on the AKE test outcome. The fixed neutral ankle position elongates the gastrocnemius and other posterior knee structures, so it was expected to yield less knee extension than the ankle relaxed in plantar flexion position.

## METHODS

### Participants

Forty-seven recreationally active college students (22 men, 25 women; mean age, 21.5±2.4 years) volunteered to participate. All participants provided consent on a form approved by the academic institutional review board. None of the participants was excluded when screened for a history of orthopedic or neuromuscular dysfunction affecting flexibility and knee extensibility restriction <20° assessed by the AKE test with the ankle relaxed in plantar flexion (AKE-PF). Testing included both right and left legs, yielding a sample of 94 legs. Data collection and intervention activities occurred in the college's biomechanics laboratory.

Sample size estimation was difficult, as the literature does not indicate variability associated with hamstrings-gastrocnemius or gastrocnemius-only stretching. Using

just the estimate of the standard deviation for hamstrings-only stretching (approximately 9°)<sup>25</sup> and considering a 5° difference due to treatment clinically significant yields a power of 80%, with approximately 50 cases per treatment level (effect size of 0.24 for treatment differences using a one-way analysis of variance).<sup>26</sup>

### Data Collection

*Pretest.* Participants arrived for AKE testing wearing shorts and a short sleeve top, having avoided strenuous exercise 12 hours prior. They removed their shoes and lay supine on a long, level and firm tabletop fitted with a crosswire device, similar to that used by Gajdosik and Lusin.<sup>23</sup> (Note: Our crosswire device was a firm wire suspended 10-12 inches above and across the tabletop. Each end of the wire was attached to a post connected to the table, allowing the participant to slide underneath the wire while atop the table. Posts for the crosswire device are visible in Figures 1 through 3.) A test administrator identified and marked the greater trochanter and lateral epicondyle of each femur with a black ink dot. Leg testing order (ie, right or left) was randomized using the software at <http://www.randomizer.org>.

Figure 1 shows the start position for the AKE-PF test. The nontest leg was secured to the table at mid-thigh to restrain the tendency for pelvic tilt and maintain a neutral pelvic position during the test. An adapted long-arm goniometer was attached to the test leg. To enhance measurement accuracy, 12-inch rulers were secured to each arm of this goniometer. Goniometer placement put the axis over the dot on the greater trochanter and the distal end over the dot on the lateral epicondyle of the femur. The proximal arm of the goniometer was held parallel to the table top by the first test administrator (P.J.R.). The anterior thigh of the test leg barely contacted the crosswire device, yielding 90° of hip flexion on the goniometer.

To complete the AKE-PF test, participants slowly extended the knee, keeping the thigh in contact with the crosswire and the ankle relaxed. Knee extension stopped when participants felt a strong, but not painful, pull in the back of the leg or when the first test administrator noted at least a 1° hip angle increase on the goniometer (indicating thigh movement away from the crosswire). At the AKE-PF end position (Figure 2), the second test administrator (D.E.) placed a digital inclinometer on the lower leg to obtain its inclination angle in reference to the horizontal. This inclinometer was calibrated to



Figure 1. Start position for assessment with ankle relaxed in plantar flexion.



Figure 2. Measurement of maximum inclination angle during assessment with ankle relaxed in plantar flexion.

the level tabletop before each testing session. The inclination angle was recorded and then converted to a posterior knee angle by adding  $90^\circ$ . Each participant repeated the AKE-PF test protocol on the other leg. Participant eligibility was based on restricted flexibility: the AKE-PF posterior knee angles had to demonstrate more than  $20^\circ$  of knee extension loss ( $\leq 160^\circ$  angle).

**AKE Test Foot Position Influence.** Participants eligible for the intervention study had knee extensibility assessed a second time, 48 hours after the AKE-PF pretest at approximately the same time of day (eg, late morning, early afternoon, late afternoon). Participants completed the same test protocol, but a lightweight heat-moldable splint was attached to the foot and lower leg to maintain the ankle in neutral (AKE-N) (ie, at  $90^\circ$ ) and prevent plantar flexion, which might allow for increased knee extensibility. At the end position (Figure 3), the lower leg inclination angle was used to calculate posterior knee angle.

**Posttest.** After the intervention phase of the study, all participants completed their AKE-PF posttest within 48 hours of their last stretching session given that the positive effects of a flexibility program may begin to diminish within 48 hours of program cessation.<sup>3,27</sup> Posttest procedures matched pretest procedures, with the same two test administrators performing the same measurement tasks. The first administrator (who could stop the test due to hip angle changes) was blinded to intervention group assignment until the completion of all posttests.

### Interventions

The selection of the hamstrings-only stretch position was based on previous research.<sup>3</sup> Gains from ham-



Figure 3. Measurement of maximum inclination angle during assessment with the ankle neutral.

string stretching in a supine position are comparable to gains from hamstring stretching in a standing position,<sup>3,27</sup> and the supine position reduces the likelihood of participants adopting a posterior pelvic tilt position, which might limit their stretching gains.<sup>15</sup> There was no research to guide selection of gastrocnemius-only and combined hamstrings-gastrocnemius stretch positions, so these stretches were based on common clinical methods that used the same supine position used in the hamstrings-only stretch. Static stretching was selected because it poses little risk of injury<sup>3,27</sup>; numerous studies show that static hamstring stretching improves flexibility.<sup>2,5-7,12,14,15,22</sup> Thirty seconds of stretch is an effective duration,<sup>2</sup> and the completion of 1 repetition per day 3 times per week for 4 weeks (ie, 12 sessions) is well within the range of frequency protocols that increase flexibility.<sup>3,27</sup> Stretching groups maintained their current activity level but added one 30-second repetition of the assigned stretch to each leg 3 times per week for 4 weeks. The control group kept their activity level consistent for 4 weeks.

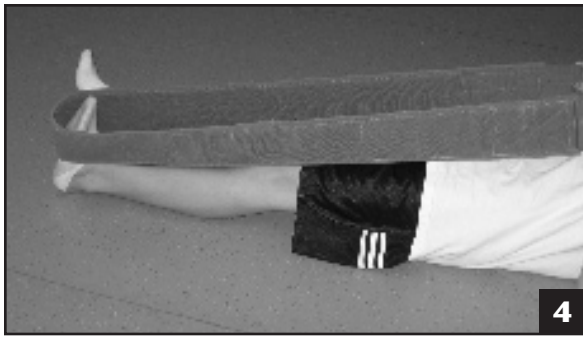


Figure 4. Gastrocnemius-only endpoint stretch position.



Figure 5. Hamstrings-only endpoint stretch position.



Figure 6. Hamstrings-gastrocnemius endpoint stretch position.

Immediately following the AKE-N test, participants were randomly assigned to one of four groups: control, gastrocnemius-only stretching, hamstrings-only stretching, or combined hamstrings-gastrocnemius stretching. Software at <http://www.randomizer.org> was used for random assignment to groups. Each participant received a demonstration of the assigned stretch and a handout with directions and a picture of the endpoint position. Participants then performed the stretch under the supervision of the second test administrator.

Directions common to all of the stretches included:

Relax your head, neck, and trunk on the floor; position yourself to feel a strong, but not painful, stretching sensation; and hold the stretch for a timed 30 seconds, then repeat it on the other leg.

The gastrocnemius-only stretch (Figure 4) group used an even pull with both hands on a nonelastic strap to move the ball of the foot toward the head, without hip or knee flexion, to create the sensation of stretch behind the knee, in the upper calf, or in both places.

The hamstrings-only stretch (Figure 5) group kept the foot of the leg being stretched relaxed in plantar flexion while adjusting stretch intensity by

sliding the entire torso closer to, or farther from, the wall to create the stretch sensation in the back of the thigh.

The combined hamstrings-gastrocnemius stretch (Figure 6) group added a gastrocnemius stretch to the hamstrings-only stretch. Participants adjusted torso position first to create the stretch in the back of the thigh, and then both hands evenly pulled on a nonelastic strap to create an additional stretch sensation behind the knee, in the upper calf, or in both places.

Each week, the stretching group participants visited the laboratory for supervision of 1 of their 3 stretching sessions and to report the other days and times during the week when they had stretched. The second test administrator coordinated all stretching-related activities (ie, group assignment, demonstration, supervision and compliance recordkeeping) to keep the first test administrator (who could stop the AKE posttest) blinded to all stretching activities.

### Design and Statistical Analysis

A pretest-posttest design with a control group was used to examine the effect of 3 different stretches on knee extensibility as assessed with the AKE-PF test. An analysis of covariance (ANCOVA) determined the effects of the stretching intervention on the AKE-PF posttest posterior knee angle across the 4 groups. AKE-PF pretest posterior knee angles served as the covariate to equalize any influences across the groups due to pretesting. A paired samples *t* test compared AKE-PF and AKE-N posterior knee angles to determine the influence of foot position on the AKE assessment. All statistical analyses used SPSS version 16 software (SPSS Inc, Chicago, Ill), with significance set at  $P < .05$ .

TABLE

## Comparisons of Control and Stretching Groups

GROUP	PRETEST POSTERIOR KNEE ANGLE (°) <sup>a</sup>	POSTTEST POSTERIOR KNEE ANGLE (°) <sup>b</sup>	SIGNIFICANCE FROM CONTROL (P) <sup>c</sup>	95% CONFIDENCE
				DIFFERENCE INTERVALS (PAIRWISE COMPARISONS)
Control (n = 28)	101.25 (2.51)	104.2 (2.25)		
Gastrocnemius (n = 16)	103.94 (3.24)	116.1 (2.96)	.012	-1.86 to -21.96
Hamstrings (n = 23)	101.22 (2.25)	115.0 (2.48)	.010	-1.81 to -19.81
Combined hamstrings- gastrocnemius (n = 22)	107.73 (2.45)	117.6 (2.57)	.001	-4.08 to -22.66

<sup>a</sup> Covariate: Pretest knee angle used for evaluation = 103.33°.

<sup>b</sup> Posttest knee angles adjusted for the use of the covariate.

<sup>c</sup> Adjusted for multiple comparisons with Bonferroni.

## RESULTS

Forty-seven participants (94 legs) completed the intervention part of the study, but 2 participants (4 legs) were disqualified for missing 2 stretching sessions within 1 week. Forty-five participants (90 legs) completed all 12 stretching sessions, with 6 of these participants completing their twelfth session early in the fifth week. One leg was excluded from posttesting because it recently sustained an ankle sprain, yielding a sample of 89 legs.

ANCOVA results indicated that stretching significantly improved knee extensibility ( $F_{3,84} = 6.64, P < .0001$ , observed power = 0.968). Pairwise comparisons revealed that all stretching groups differed from the control group at varying levels of significance (Table). The combined hamstrings-gastrocnemius group was most different from the control group, with the 95% confidence interval for differences ranging from 4.08° to 22.66° ( $P < .001$ ). None of the stretching groups differed from each other.

Forty-seven participants (94 legs) completed the AKE-PF and AKE-N tests. Results of a 2-tailed paired samples *t* test indicated significantly ( $t_{93} = 5.085; P < .001$ ) greater knee extensibility ( $102.95^\circ \pm 12.67$ ) with the AKE-PF test compared with the AKE-N test ( $96.97^\circ \pm 11.53$ ). The 95% confidence interval of mean differences spanned 3.64° to 8.31°.

## DISCUSSION

The primary goal of this study was to examine the effectiveness of 3 different stretches on knee extensibility during a 4-week period. The influence of the gastrocnemius was of particular interest. Statistically, all 3 stretching programs significantly improved knee extensibility as determined by the AKE-PF test. This finding was not surprising, as the volume of static stretching completed

in this study (ie, one 30-second repetition 3 times per week for 4 weeks) is well within the duration and frequency range of successful stretching programs.<sup>1</sup> For example, one 60-second static stretch once per week for 3 weeks significantly increased (mean = 5.7°) knee extensibility.<sup>3,27</sup> At the other extreme, 5 repetitions of a 30-second static stretch 3 times per week for 8 weeks also significantly increased knee extensibility (mean = 11.2°).<sup>3,27</sup> Thus, a stretching program that incorporates one 30-second repetition of the investigated stretches 3 times per week for 4 weeks has potential to increase knee extensibility.

Unexpectedly, there were no statistically significant differences among the stretching groups. All participants had enough posterior leg flexibility loss that each stretching program improved knee extensibility. This finding supports clinical consideration of stretching just the gastrocnemius to increase knee extensibility. Others have not investigated the influence of gastrocnemius-only stretching on knee extensibility, but gastrocnemius stretching is known to benefit the range of available dorsiflexion.<sup>28,29</sup> Increased knee extensibility with gastrocnemius stretching is most likely due to the posterior location of the gastrocnemius, spanning the knee and ankle. Stretching this 2-joint muscle will decrease tautness for the entire muscle, as opposed to its crossing at a single joint, allowing gastrocnemius tautness to influence knee extensibility. For this sample of healthy college-aged participants, gastrocnemius stretching alone was equivalent to hamstring stretching alone and combined hamstring and gastrocnemius stretching for improving knee extensibility as determined by the AKE-PF test.

Ninety-five percent confidence intervals (Table) indicated that the combined hamstrings-gastrocnemius

group had the largest minimum difference ( $4.08^\circ$ ) compared with the control group. This minimum difference ( $4.08^\circ$ ) is higher than the minimums of the 95% confidence intervals for the gastrocnemius-only ( $1.86^\circ$ ) and hamstrings-only ( $1.81^\circ$ ) stretching groups. A  $4^\circ$  minimum may approach clinical relevance. These findings highlight the need for further investigation to determine combined hamstrings-gastrocnemius effectiveness, compared with other stretches designed to improve knee extensibility. Combined hamstrings-gastrocnemius group changes were statistically the same as the other stretching groups, but using a single stretch to target more of the 2-joint muscles that span the posterior knee may be an efficient way to create reliable and clinically significant increases in knee extensibility.

The secondary purpose of this study was to determine the influence of a fixed neutral ankle position on the AKE test. Results indicated a significant mean decrease of  $6^\circ$  in knee extension with the ankle neutral as opposed to relaxed in plantar flexion. These findings are similar to those of Gajdosik et al.,<sup>24</sup> who assessed hamstring flexibility with the SLR ( $n = 22$ ) comparing fixed dorsiflexion with relaxed plantar flexion positions. Ten degrees of fixed dorsiflexion decreased knee extension in both active ( $9.1^\circ \pm 7.5^\circ$ ) and passive ( $10.1^\circ \pm 5.1^\circ$ ) versions of the SLR.<sup>24</sup> Use of a fixed ankle neutral position in this study, as opposed to  $10^\circ$  of fixed dorsiflexion, could have narrowed the difference between the AKE-N and AKE-PF conditions. Forced dorsiflexion may decrease knee extension because it increases the resting tension of posterior knee structures that also span the ankle, such as the sciatic nerve,<sup>30</sup> gastrocnemius, skin, and subcutaneous connective tissues.<sup>24</sup> A neutral ankle position may also increase the tension in these structures. Increased resting tension in the posterior anatomical structures distal to the knee decreases the active range of knee extension, reemphasizing the need to standardize the test procedure<sup>24</sup> and monitor foot position during test completion.

Using both plantar and dorsiflexed foot positions in the AKE test might provide clinicians with more information about the influence of 2-joint posterior knee and ankle structure tautness on knee extensibility. This information could be useful in designing patient-specific rehabilitation protocols, such as those for patients who participate in closed chain activities where knee extension occurs from a dorsiflexed foot position. Comparison of test results from both foot positions could

provide additional information about knee flexibility<sup>24</sup> and help clinicians design interventions to address knee pathology.

#### LIMITATIONS

Use of healthy college-aged participants in this study limits generalization to individuals with injured lower extremity tissues. Observed power of findings was strong, but an appropriate sample size was difficult to estimate given lack of published data for gastrocnemius-only and combined hamstrings-gastrocnemius stretching routines; thus, 95% confidence interval ranges should be examined to discern the clinical relevance of findings. Hip flexor and gastrocnemius tautness were not assessed, but random assignment of participants to groups should have randomly distributed any potential influence of preexisting hip flexor or gastrocnemius tautness on the findings. Restraint of the nontest leg was also incorporated to minimize the influence of hip flexor tautness by inhibiting pelvic tilt. Future studies should assess hamstring and gastrocnemius flexibility independently to further the understanding of combined hamstrings-gastrocnemius and gastrocnemius-only stretching on knee extensibility. Improved understanding of protocols that use these stretches could facilitate matching the most effective knee extensibility program to specific patient populations.

#### CONCLUSION

AKE-PF test results indicated significant knee extensibility increases in healthy college-aged participants when stretching the gastrocnemius only, the hamstrings only, or simultaneously stretching the hamstrings and gastrocnemius during a 4-week program that required one 30-second stretch 3 times per week. Findings also demonstrated decreased knee extensibility with completion of the AKE test with the ankle in neutral, as opposed to relaxed in plantar flexion. Given these results, clinicians should consider the inclusion of gastrocnemius stretching in treatment plans designed to improve knee extensibility and monitor foot position during the AKE, perhaps using both plantar and dorsiflexed positions to gather more information regarding the sources of knee inextensibility. ■

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