INTERNATIONAL JOURNAL OF -EXERCISE SCIENCE-

Original Research

Comparison of a Low Load Eccentric Training Protocol and a Static Stretching Protocol on Hamstring Muscle Flexibility

Nancy Henderson‡, Haley Worst‡, Ryan Decarreau‡, Dixie Edalgo*, Hunter Lewis*, James Rowe*

Department of Clinical Sciences, Georgia Southern University, Savannah, GA, USA

*Denotes student, ‡Denotes established investigator

Abstract

International Journal of Exercise Science 18(8): 263-274, 2025. https://doi.org/10.70252/MRDG6392 The purpose of this study was to compare eccentric strengthening to static stretching for increasing hamstring flexibility. Sixty-three asymptomatic participants were recruited via convenience sampling. Nineteen participants did not meet the inclusion criteria, thus leaving 44 participants. Inclusion criteria included hamstring tightness defined using the passive knee extension test (PKE). Exclusion criteria included a history of any lower extremity injury, including hamstring injury, within the past 12 months. Participants were randomized into one of three groups: Nordic Hamstring Exercise (NHE) eccentric group, static hamstring stretching, or control group. Hamstring flexibility was assessed, via the PKE, at baseline, 3 weeks, and six weeks. Between and within group differences in hamstring flexibility were assessed using a mixed model ANOVA. The analysis yielded a significant time x group interaction (< 0.05). At six weeks, both the static stretching and eccentric group had greater improvements in flexibility compared the control group (p < 0.001). This study adds to the body of research by demonstrating the positive effect of eccentric training on gross muscle length. It revealed the NHE results in similar increases in hamstring flexibility when compared to static hamstring stretching. As a result, either stretching or eccentric training can be used effectively to address hamstring flexibility deficits.

Keywords: Nordic hamstring exercise, muscle length, injury prevention, rehabilitation

Introduction

Stretching is one of the most clinically utilized methods for improving muscle length and flexibility.[1] Flexibility can be defined as the ability of a muscle to lengthen and allow one or multiple joints to move through a range of motion.[2] Stretching interventions, including static, proprioceptive neuromuscular facilitation, and ballistic have been shown to be effective for improving flexibility.[2,3,4] Flexibility of the hamstring muscle group has been extensively researched because of its possible association with an increased risk of hamstring strain injury. A direct association between hamstring stretching and hamstring strain injuries has not been established with most studies demonstrating no effect on injury rates.[4,5,6] The exception is a 2003 study which showed less than 90 degrees of elevation via the straight leg raise was correlated with hamstring strain injuries in soccer players.[7] Additionally, static stretching of the hamstring

*Corresponding Author: Nancy Henderson; Email:nhenderson@georgiasouthern.edu

musculotendinous group has also been shown to influence patella tendinosis, a decreased risk of lower limb sprain/strain injuries, and low back injuries.[4,5,8]

The American College of Sports Medicine recommends static stretching be held for 30 seconds, two repetitions a day, and two times a week to increase hamstring flexibility. A 2012 systematic review indicates a stretching program initiated over a six-week period is beneficial in improving hamstring flexibility.[9] Static stretches held longer than 60 seconds may have a negative impact on muscle strength.[10,11] This deficit in strength does not appear to be present with static stretches performed for less than 60 seconds, with no difference in flexibility improvements.[12,13] Changes in flexibility after a single stretching episode are believed to be related to alterations in viscoelasticity or stretch tolerance (ST). Stretch tolerance, or the sensation felt when stretching, is a short-term subjective measure of flexibility, lasting approximately 30 minutes.[12,14] Repeated sessions of static stretching have been reported to result in longer-term increases in ST.[2]

Recently, eccentric exercise has also been shown to influence muscle flexibility.[2,15,16,17] The use of eccentric exercise to impact hamstring flexibility has yielded studies with conflicting results. Nelson and Bandy (2004) used a 6-week supine eccentric hamstring training protocol that improved hamstring flexibility 12.79 degrees.[18] A 2019 study utilized an 8-week eccentric leg curl and demonstrated a 6.9 degree increase in passive knee extension (PKE) flexibility gain.[17] A case study reported increased hamstring stretch tolerance (7.6 degrees) in previously injured athletes following six weeks of training with the Nordic Hamstring Exercise (NHE).[19] Delvaux et al (2020) looked at a group of 4 eccentric based hamstring exercises (including NHE) over a 6-week period and found an 11.4 degree increase in hamstring passive flexibility.[32] The use of 4 different eccentric exercises makes it difficult to determine if one of the exercises had a greater effect on the change in length of the hamstring muscle. Alternatively, other authors studied a 4- and 10-week training program, respectively, using the NHE and demonstrated a positive impact on hamstring eccentric peak torque, but no change in hamstring flexibility.[20,21]

The NHE is a simple hamstring eccentric exercise that is easy to learn, easily scaled, and requires minimal or no equipment. Eccentric exercise, such as the NHE, has been shown to have a positive impact on sprint times, jumping ability, optimum hop frequency, increase overall strength, and decreased risk of initial and subsequent hamstring injury.[18,22,23,24,25] The NHE has also been used in previous research to develop rehabilitation guidelines and injury prevention interventions for hamstring strains.[14,26,27] One of the limitations of the NHE is patient compliance. Due to high levels of eccentric stress, muscle soreness is a common complaint when initiating a NHE program.[28] Decreasing initial NHE exercise protocol volume may decrease muscle soreness, thus improving subject compliance. Presland (2018) evaluated the effect of low volume (128 repetitions) vs high volume (440 repetitions) NHE and demonstrated similar increases in eccentric knee flexor strength (High Volume: 28%, Low Volume: 34%) and fascicle length with low volume training and high compliance levels (100%) (36).[29] The effect of low volume NHE on hamstring flexibility is unknown.

Thus, the aim of this study was to compare low volume NHE training to static stretching to determine the most effective method for increasing hamstring flexibility. An increase in

hamstring flexibility was expected among both the eccentric loading group and static stretching group; however, a greater increase within the eccentric loading group was predicted.

Methods

Participants

The current study was approved by a local University's Institutional Review Board. This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.[30] Prior to beginning the study, all participants read and signed an informed consent document.

Asymptomatic individuals, aged 18-40, were recruited via convenience sampling for the current study. Participants were included if they exhibited reduced hamstring muscle flexibility of at least one leg, defined by less than 160 degrees knee extension motion when measuring the popliteal angle using the PKE.[3] Individuals were excluded from the study if they reported any lower extremity injury, including hamstring injury, within the past 12 months. Data collection took place on the University's campus.

Sixty-three participants were recruited for the study. Nineteen individuals were excluded after baseline testing, due to not meeting inclusion criteria, leaving forty-four participants (45% male; mean age = 23.1 +/- 3.6 years old) who were enrolled in the study. All included participants had both legs qualify for the study based on inclusion and exclusion criteria, yielding 88 separate data points for the study. Each leg was treated as a separate data point in the sample.

The sample size was calculated using data from a study by Nelson and Bandy.[18] The between group factor was group and the within group factor was time, yielding a 3 x 3 factorial design. Accounting for a 0.05 type 1 error, the analysis yielded a total of 57 data points needed to achieve 80% power. Accounting for 10% attrition, a final sample size of data points was used.

Protocol

This prospective, randomized, controlled trial compared the effectiveness of two interventions to improve hamstring flexibility: eccentric hamstring strengthening and static hamstring stretching. The outcome measure was hamstring flexibility assessed using the passive knee extension test.

All participants were randomized into one of the following groups: eccentric hamstring strengthening, static hamstring stretching, and control. The randomization schedule was determined using an online random number generator and simple random assignment. Group allocation was revealed after baseline testing. A reliability study, which assessed intra-rater reliability of the PKE test on the three examiners, was conducted prior to data collection. Intra-class correlation coefficients were calculated and the examiner with the highest ICC values on the PKE conducted all assessments. The three examiners (DE, JR, HL) were second year Doctor of Physical Therapy Students. They conducted the data collection phase under the supervision

and guidance of licensed Physical Therapists (NH, HW, RD), each with more than 10 years of clinical experience. Additionally, the licensed Physical Therapists held training sessions for the examiners prior to commencing data collection.

During baseline testing, all participants completed a demographic questionnaire and hamstring flexibility was assessed using the PKE, to determine hamstring flexibility. The prone knee extension (PKE) test is considered the gold standard for clinical testing of hamstring flexibility as it reduces the contribution of other body segments, allows a unilateral assessment of muscle flexibility, and limits the contribution of neural tension on measurement outcome.[3] To begin the PKE assessment, each participant laid supine on a plinth with both lower extremities fully extended for five minutes to allow for relaxation of lower extremity musculature, consistent with previously used guidelines.[31] The examiner then passively flexed one hip to 90 degrees while keeping the knee flexed to 90 degrees, measured with a standard goniometer. The contralateral lower extremity was secured in full knee extension utilizing a strap placed over the distal thigh of the participant. The lower extremity being measured was stopped at 90 degrees of hip flexion by a custom-made box to allow the examiner to passively extend the knee until a strong, but tolerable stretch was felt in the posterior thigh (Figure 1). Next, the examiner measured the popliteal angle while looking away from the goniometer while a second examiner recorded the value to maintain a blinded reading. Each limb was measured three times and the average of the three measures was used for data analysis.

Figure 1. PKE assessment

Throughout the study, all participants were advised to continue normal activities. Written and video instructions were provided for both the eccentric and stretching groups prior to training. Each training session began with a standardized dynamic warm-up consisting of two sets each of butt kickers, a light jog, karaoke, and high leg kicks. For those participants in the eccentric and static stretching groups, each participant attended training sessions twice per week for a total of six weeks, with at least 2 days of rest between sessions. Participants in the control group only attended testing sessions. Testing sessions were conducted at baseline, 3 weeks, and 6 weeks, and occurred 24 - 48 hours after the training session.

Participants in the eccentric group performed the NHE (Figure 2) as their exercise regimen. Each participant was positioned prone on a plinth with the edge of the plinth at the talocrural articulation. An adjustable strap was placed across both lower extremities just proximal to the malleoli to keep the leg straight and stabilize the pelvis. The participant started in a high kneeling position with arms on the chest and hips extended. Participants then lowered their bodies as slow as possible until they could no longer maintain control of the descent. After each repetition, subjects utilized a hand walking technique to transition from prone back to a high kneeling position to prohibit concentric activation of the hamstrings. Each Nordic hamstring curl set was performed for an established number of repetitions followed by a 30 second rest break (Table 1).

Figure 2. Nordic Hamstrings Curl

Table 1. Eccentric Strengthening Protocol.

Training Week	Sets	Reps
1	1 set	6 reps
2	1 set	6 reps
3	2 sets	6 reps
4	2 sets	6 reps
5	3 sets	6 reps
6	3 sets	6 reps

Participants in the static stretching group performed a seated, unilateral hamstring stretch on each lower extremity. Each participant began by sitting at the edge of a standard chair with one lower extremity fully extended. The contralateral lower extremity was placed in a bent position at approximately 90 degrees of hip and knee flexion. Participants were instructed to "place hands on hips, look straight ahead, keep back and neck in a straight line, and squeeze shoulder blades together." The participant then bent at the waist to move the chest toward the knees until a comfortable, pain-free stretch was felt in the back of the straight leg (Figure 3). This position was held for 30 seconds, and two repetitions were performed on each lower extremity, alternating legs between each repetition to allow for a 30 second rest. No difference in hamstring flexibility gains have been noted based off position the stretch is performed in and the seated position has been shown in interventional studies to increase hamstring flexibility between 5.7-11.2 degrees via PKE.[35]

Figure 3. Static Hamstrings Stretch.

Statistical Analysis

For the reliability study, intra-rater reliability for three examiners was assessed by calculating intra-class correlation coefficients (model 3). Measures of central tendency were used to describe the data and one-way independent ANOVA and Chi square tests were conducted to assess differences in baseline and demographic variables. Assumptions were analyzed prior to conducting a mixed model ANOVA, which was used to assess between and within group differences in hamstring flexibility across time. Time was the within group factor (baseline, 3 weeks, 6 weeks) and group (static stretching, eccentric strengthening, control) was the between group factor. When significance was found, Bonferroni adjusted change contrasts were performed. If the Bonferroni adjusted change contrasts yielded significance, Cohen's D effect sizes were included. The authors used the following interpretation for effect sizes: 0.2 = small; 0.5 = medium; 0.8 = large. Lastly, missing data was thought to be missing at random; therefore, mean substitution was utilized for data analysis. SPSS, version 25, was used for analyses with an alpha level of 0.05.

Results

For analysis, each lower extremity counted as its own data point, yielding a total of 88 data points for analysis. Descriptive data is listed in Table 2. The examiner with the highest intra-rater reliability yielded an ICC of 0.98.

Table 2. Baseline Characteristics

	Stretching	Eccentric	Control
Age	23.5 (4.3)	22.8 (1.6)	24.5 (3.6)
Gender (% female)	57% (9)	50% (8)	50% (7)
Dominant leg (right)	93% (13)	100% (16)	88% (12)
% people who exercise 1-2x/ week	71% (10)	63% (10)	64% (9)
% people who do not stretch	57% (8)	69% (11)	63% (9)

*Age: mean (standard deviation), Remaining demographics: percentage (*n*)

There were (3) missing participants from the 3- and 6-week follow-ups, constituting (6) total missing data points. Two participants (4 data points) were from the stretching group and (1) participant (2 data points) was from the eccentric training group. No statistical difference ($p > 0.05$) in baseline variables was noted between the three groups (Table 3).

Prior to conducting the mixed model ANOVA, assumptions were assessed. A Greenhouse Geisser correction was used as sphericity was violated. Additionally, homogeneity of variance was violated for the 6-week time frame but met for the baseline and 3-week time frames. Considering we had similar sample sizes in each group, the authors concluded that a mixed model ANOVA was robust enough to withstand violating homogeneity of variance for one

timeframe. The results from the two tailed mixed model ANOVA indicated a significant group x time interaction ($F_4 = 14.623$; $p < 0.001$).

Table 3. PKE Measurements for Hamstrings Flexibility

Group	Baseline	Week 3	Week 6
Stretching	151.30 (7.42)	155.71 (7.76)	162.64 (6.23)
Eccentric	150.92 (9.40)	157.51 (8.94)	163.61 (10.27)
Control	153.06 (4.97)	153.55 (6.46)	157.51 (5.15)

Mean (standard deviation)

Post hoc tests were performed and demonstrated that all three groups improved similarly from baseline to three weeks ($p > 0.05$); however, significant differences were noted from three weeks to six weeks. At six weeks, the stretching group had improved significantly more than the control group (mean difference = 5.12 degrees; effect size= 0.79; $p < 0.001$). Similarly, at six weeks, the eccentric group had greater improvement compared to the control group (mean difference = 6.10 degrees; effect size = 0.87; $p < 0.001$). There was no significant difference between the eccentric and stretching groups at any of the time frames ($p > 0.05$; Table 3).

Discussion

The results of this study support the findings of previous research suggesting that utilizing eccentric hamstring exercises, as in the NHE, and static stretching yield similar gains in flexibility.[2] The increases in PKE range of motion of 12.8 and 11.4 degrees in the eccentric and static stretching groups, respectfully, are similar gains to those previously reported.[16,17,31,32,33,35,38]

The timing of hamstring length changes is consistent with previous research, with an increase noted as early as 2-4 weeks after starting an eccentric or stretching program.[4,15,25] Although the hypothesis that the NHE would be more effective than static stretching was not supported, both interventions showed a significant increase in hamstring flexibility from pre- to post-testing compared to the control group. Much of the research to date regarding eccentric training and muscle adaptation has focused on muscle architecture (fascicle length, fascicle angle, pennation angle, cross sectional area, muscle volume) as opposed to gross muscle length.[4,14,15,34] From a clinical standpoint, gross muscle length, as was used in the current study, is a more time efficient and less costly measure to track longitudinal changes, as muscle architecture requires the use of ultrasonography or MRI. The correlation between fascicle length changes and gross muscle length change has demonstrated conflicting results, likely due to the estimation of fascicle length utilizing small scanning windows with ultrasound and region-specific adaptations within the muscle after training.[35,36,37] Gross muscle length, although more clinically feasible, is not without limitations. It is not possible to tell with the current study design what was responsible for the changes in hamstring flexibility (i.e., …changes in tendon and/or muscle stiffness, stretch tolerance, muscle architecture).

Static stretching has been shown to have a positive effect on stretch tolerance with limited changes noted in muscle morphology.[13] Although most acute and chronic stretching studies demonstrate an increase in muscle range of motion, an impairment in performance has been consistently reported.[35,38] This has led to static stretching falling out of favor in performance training for professional and recreational athletes. A recent review by Lima et al demonstrated that shorter duration stretching (< 45 seconds) and stretching to a mid-point of discomfort intensity decreased the negative performance effects of static stretching.[13] This finding is supported by several studies.[10,11] Although static stretching can be prescribed to limit performance decrements, a link to enhancing performance, or a clear correlation with performance variables such as body composition, muscle endurance, or muscle strength has not been demonstrated.[2,36] In contrast, eccentric training has been shown to improve sprint times, jumping ability, optimum hop frequency, increase overall strength, and decrease risk of initial and subsequent hamstring injury.[22,23,24,25,30] This provides some theoretical support for the use of eccentric training when not only a change in muscle length, but also an improvement in physical performance is desired.

The NHE was used in this study due to the effectiveness that it has demonstrated for hamstring injury risk and prevention. This is despite some questions regarding its utility secondary to knee dominant nature, minimal amount of hamstring lengthening during performance, and preferential activation of semitendinosus over biceps femoris.[14] It could be argued that the hamstrings would be better trained with a combination of hip flexion and knee extension, more closely replicating the common mechanism of injury seen in the late swing phase of sprinting.[33] Although this argument makes intuitive sense, minimal evidence exists to support the superiority of combined hip flexion and knee extension training (i.e., …Razor Curls).[14,17] Similarly, training at longer muscle lengths has not been shown to lead to greater increases in hamstring length.[4,37] Several factors may impact this finding. Muscle adaptation to eccentric training likely is related to the combined effects of exercise intensity, volume, and muscle length at which the exercise is performed.[23] Of these, the intensity of the exercise may be the most important for muscle adaptation.[25] A 2017 study demonstrated that the NHE had the highest eccentric activation of the biceps femoris when compared to 9 other commonly performed lower extremity strengthening exercises.[14] This may be related to the need to maintain hip extension throughout and the longer moment arm of the biceps femoris at the hip.[14,37]

The current study is not without limitations. Although a low volume of NHE was effective at increasing hamstring flexibility and compliance was high, a measure of muscle soreness was not recorded during the intervention. It is unclear if compliance was related to a decrease in soreness given the unaccustomed exercise protocol. The protocol we used did not allow for progressive increases in intensity during the 6-week intervention. Bourne et al. added weight held to the chest (2.5 - 20kg) when participants were able to completely stop the movement in the final 10 - 20 degrees of range of motion to ensure overload over a 10-week protocol and demonstrated an increase in fascicle length.[14] Similarly, Pollard et al. compared body weight and weighted NHE and showed a significant increase in fascicle length after 6 weeks of weighted NHE when compared to body weight NHE.[17] Despite the improvement noted in hamstring flexibility from week 3 to week 6 of the current investigation, it is unknown if this would have increased further

with individualized progressive overload of the NHE. Lastly, the study was performed with healthy recreational athletes. It cannot be determined if a similar positive impact would be seen in a higher level of athlete or in those who have suffered a hamstring strain.

Several areas for future research in this area exist. The current study utilized recreationally active individuals. Recreating these results in competitive athletes with a longer training history would be important if this intervention was to be implemented with this population. Future work looking at the volume of eccentric load needed to maintain an increase muscle length over a post-intervention period (12 - 24 weeks) would be important for rehabilitation and strength and conditioning practitioners. Finally, the NHE has been extensively studied to assess its impact on hamstring strength and injury prevention. Future research examining the impact of eccentric exercise on upper extremity muscles such as the pectoralis major and latissimus dorsi may have implications for performance and injury prevention for upper extremity athletes.

In conclusion, the use of low volume NHE in recreationally active individuals is as effective as static stretching when the intention is to increase hamstring muscle length when measured via the PKE test. In individuals with time constraints or heavy training volumes, such as athletes, low volumes of NHE may be substituted for passive stretching when the goal is increased muscle length with the added benefit of a strengthening stimulus.

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