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Two Stretching Treatments for the Hamstrings: Proprioceptive Neuromuscular Facilitation Versus Kinesio Taping

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Context: Recent studies have shown that the static stretch (SS) may adversely affect leg-muscle performance. ***Objectives:*** The authors examined the short-term effects of 2 stretching exercises on hamstrings muscle before and after exercise. ***Design:*** Crossover. ***Setting:*** Laboratory. ***Participants:*** 9 healthy, physically active men. ***Interventions:*** There were 3 protocols in a randomized order with a 7-d interval: nonstretching (CON protocol), hamstrings static stretching (SS) with proprioceptive neuromuscular facilitation (PNF), and SS with kinesio-taping application on the hamstrings. ***Main Outcome Measures:*** Outcome measures included first-felt and maximum tolerant-felt range of motion (FROM and TROM), maximal knee-flexion peak torque (PT) at 180°/s, and hamstrings muscle stiffness. ***Results:*** Groups were not different at prestretching in terms of hamstrings flexibility, PT, and muscle stiffness. At poststretching, both stretching protocols showed significant increases in FROM and TROM ($P < .05$). Stiffer hamstrings muscle and decreased PT were found in both SS+PNF and CON protocols ($P < .05$). However, there was no significant difference in the SS+Taping protocol ($P > .05$). ***Conclusion:*** The stretching protocols improve hamstrings flexibility immediately, but after exercise hamstrings peak torque is diminished in the SS+PNF but not in the SS+Taping group. This means that SS+Taping can prevent negative results from exercise, which may prevent muscle injury.

Keywords: stretching exercise, muscle performance, hamstrings, taping

Despite controversy about the effects of stretching exercises, hamstrings stretching is still commonly used as a primary part of warm-up procedures for strength improvement, injury prevention, and reduction of delayed-onset muscle soreness.[1,2] Recent reviews have suggested that stretching treatments enhanced flexibility[3] and increased hamstrings performance (ie, eccentric and concentric peak torque [PT]).[4] On the other hand, decreases in maximal voluntary isometric contraction of the hamstrings,[5,6] vertical jump,[7] and isokinetic PT[5,8] have been reported after stretching, especially with static stretching. These controversial results may be due to different types of stretching, stretching treatments, and the populations of different samples. Nevertheless, if a stretching program not only increases flexibility but also improves muscle performance and possibly reduces the risk of injury, appropriate stretching should be incorporated in an exercise routine.

Considering the potential relationship between stretching exercise and muscle performance,[9,10] an appropriate stretching technique and treatment may be adjusted to enhance the positive effects of the technique. Presumably, stretching can increase muscle length.[9,10] According to the length–tension relationship, lengthening muscle reduces force production due to decreased cross-bridge formation and subsequently reduces the muscle's ability to efficiently generate activity.[11] Thus, muscle contraction in a stretching technique can reduce the lengthening effect of muscle and subsequently increase its contraction ability.[12–14] The proprioceptive neuromuscular facilitation (PNF) technique was originally developed by Knot and Voss[15] and involved proprioception in the treatment of paretic patients. This technique is a stretching intervention with isometric contractions that has been shown to produce greater increases in hamstrings flexibility[3,14,16] and greater muscle activity than static stretching,[14,16] which may enhance current stretching practices by athletes. It is believed that the PNF stretching technique can be used to increase muscle flexibility and produce better muscle performance.[14,16]

Kinesio taping has been widely used in athletes to prevent sports injuries, as the specialized grain and elasticity of the kinesio tape is applied to the skin. Kinesio tape was applied from the origin to the end of hamstrings muscle, which was believed to provide support for the muscle and to increase muscle tone.[17] Some different beneficial effects have been shown, including improvement in muscle activity (electromyography, EMG), muscle strength,[17] joint-position perception,[18,19] and force sense.[20]

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Several possible explanations are provided. First, tactile stimulation throughout the kinesio taping delivers more signals to the central nervous system for information integration.[21] Second, fascial-tissue realignment throughout the kinesio taping produces an optimal length–tension relationship and increases muscle force.[22] One study found an acute decrease in muscle strength after static stretching,[5] while others found that PNF stretches produced greater hamstrings flexibility[3,14,16] and increased muscle activity (EMG).[16] Thus, we hypothesized that stretching effects would be better with the combinations of either static stretching plus PNF (SS+PNF) or static stretching plus kinesio taping (SS+KT) than with stretching only. In addition, effects were also tested between SS+PNF and SS+KT on range of motion (ROM), PT, and muscle stiffness.

Methods

Participants

Nine male students (age 23.9 ± 3.1 y, height 174.1 ± 7.1 cm, weight 64.9 ± 5.2 kg) without a prior history of lower extremity injury or neurological disorder and no low back pain were recruited from a university to participate in this study. These subjects were recreationally active college students and performed 3 to 5 hours of regular exercise per week. To validate the effect of stretching techniques, subjects with short hamstrings were selected. Short hamstrings were defined as a hip angle of less than 80° during maximum manual passive straight-leg raising.[23] All participants provided written informed consent before testing.

Experimental Design

We employed a 1-group pretest-posttest quasi-experimental design. One group of subjects performed 3 experimental interventions with a 7-day interval between tests. The 3 interventions were nonstretching (control), SS+PNF, and SS+Taping. The interventions were randomized using a Latin-square design. The outcome measures were isokinetic concentric contraction (180°/s) PT, muscle flexibility, and muscle stiffness after stretching and after dynamic exercises for each experiment (Figure 1).

Stretching, PNF, and Kinesio Taping

In the SS+PNF technique, SS was an unassisted modified hurdler stretch, with the subject sitting on the floor with 1 knee bent so that the sole of foot was next to the thigh of the opposite leg. The hamstrings in the dominant leg was stretched by having the subject extend his leg and reach for his toes, and this position was held at mild discomfort in the hamstrings. The dominant leg was determined as the one with which subjects preferred kicking. The SS was held in this position for 30 seconds with 30-second recovery periods between stretches repeated 5 times.[24] The PNF contract-relax-agonist-contract stretch was applied according to methods of Rowlands et al.[25] The participant lay in a supine position. One investigator took the leg slowly to its end point (which was defined as the point at which the subject felt mild discomfort but no pain) while the second investigator firmly stabilized the unstretched leg on the table. The participant was asked to perform a maximal voluntary isometric contraction of the antagonist muscle group (hamstrings) for 10 seconds, followed by 5 seconds relaxation. Then the participant contracted the agonist muscle (quadriceps) and the first investigator moved the leg to a new end point (mild discomfort and without pain), which was held for 10 seconds. This PNF technique was repeated 3 times (Figure 2).

In the SS+KT interventions, the SS was the same as described previously, with kinesio tape applied to the hamstrings (Figure 3). Vithoulka et al[19] proposed that application of kinesio tape from muscle origin to insertion may improve muscle-contraction efficiency. Thus, participants were taped with a Y-shaped kinesio tape

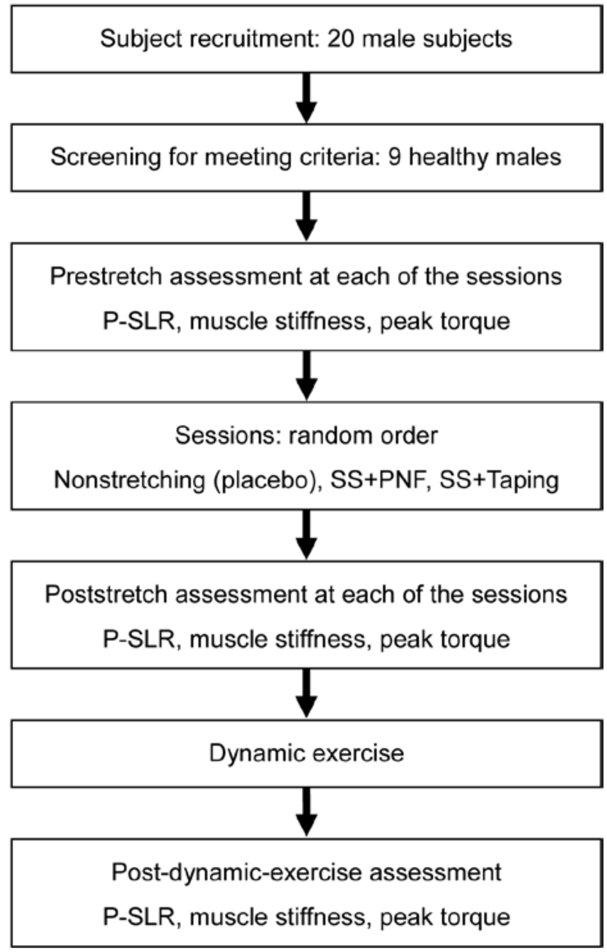

Figure 1 — Participant flow diagram. P-SLR, passive straight-leg raises; SS+PNF, static stretch with proprioceptive neuromuscular facilitation; SS+Taping, static stretch with kinesio taping; dynamic exercise, 25 consecutive maximal-effort reciprocal concentric/eccentric contractions on an isokinetic dynamometer at an angular velocity of 180°/s.

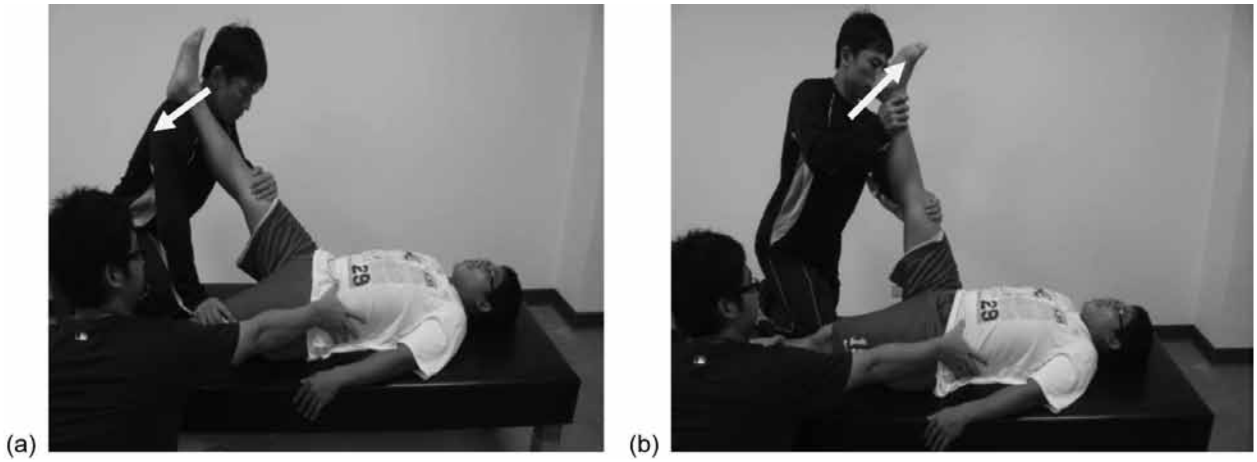

Figure 2 — The proprioceptive neuromuscular facilitation stretching exercise (contract-relax-agonist-contract). (a) Isometric contraction of the hamstrings against the investigator's shoulder for 10 seconds (arrow). After 10 seconds of relaxation, (b) concentric contraction of quadriceps to move the leg to a position for further stretching the hamstrings for 10 seconds.

Figure 3 — The tape application on the hamstrings. The subject lay on his stomach on the table. Then, a physical therapist applied the kinesio tape from the ischial tuberosity to the medial and lateral epicondyle of the tibia at the hamstrings. During the application, the first 5 cm of tape was not stretched and acted as the anchor, and the remainder was stretched to 120% of the original length.

applied to the hamstrings (from the ischial tuberosity to the medial and lateral epicondyle of the tibia) by a physical therapist. The first 5 cm of tape was not stretched and acted as the anchor, and the remainder was stretched to 120% of its original length.[26] The subjects in the control group remained seated with both knees flexed and legs dangling from the table for the same duration (~5–6 min).

The Dynamic Exercise (Short-Stretching Cycle)

Following the stretching experiment, every subject performed a secondary activity (25 consecutive maximal-effort reciprocal concentric/eccentric contractions, with approximate effort duration of 20–30 s) on an isokinetic dynamometer at an angular velocity of 180°/s exercise, immediately.[27] After the dynamic exercise (no rest period), hamstrings PT, flexibility and stiffness were measured.

Outcome Measures

Hamstrings PT. Isokinetic testing was performed to assess hamstrings muscle function using a Cybex 6000 isokinetic dynamometer (Lumex, Inc, Ronkonkoma, NY). The participant was seated with the thigh at an angle of 85° to the trunk. The mechanical axis of the dynamometer was aligned with the lateral epicondyle of the knee, and the trunk, waist, thigh, and chest were stabilized with belts to avoid compensatory movement. Knee ROM was set at 0° to 90°.

The participants carried out a standardized warm-up composed of 5 submaximal concentric contractions at 180°/s before each test session. After a 2-minute rest period, they were asked to perform 3 maximal voluntary concentric contractions of the dominant knee-flexor muscles (hamstrings), and the concentric PT of the hamstrings was measured at 180°/s.[27] A 45-second rest period was permitted between sets. Gravity-corrected PT at test speed was calculated as the mean PT over the 3 repetitions. Only torque data obtained during the isokinetic phases of the movement were included in the analysis.

Hamstrings Flexibility. Hamstrings flexibility was evaluated using passive straight-leg raises (P-SLR) based on previous studies.[12,23,28] The subject lay supine on a padded plinth, and both waist and the nonstretched leg were fixed by a strap. The first examiner held the subject's dominant leg, the one to be stretched, by the ankle and knee (to ensure full extension), and the inclinometer (Isomed, Portland, OR) was placed over the distal tibia.[28] The nonstretched leg was fully extended at the knee by a strap, and the second examiner held the anterosuperior iliac spine to avoid posterior rotation. During the test, 2 ROMs of hip flexion were measured. First, an examiner passively moved one of the straightened limbs until the participant first felt a mild sensation of pain (FROM), and then until maximum tolerable tension (TROM) in the posterior thigh that could not be increased further.[23] This test was repeated 3 times, and the mean of 3 measures was used for analysis.

Hamstrings Stiffness. Hamstrings muscle stiffness was quantified by a Myotonometer (Neurogenic Technologies, Inc, Missoula, MT), a computerized meter-type device to measure relaxed muscle-stiffness levels. The head of the Myotonometer probe was placed along the longitudinal axis of the right biceps femoris muscle at 50% of the distance from the ischial tuberosity to the medial epicondyle of the tibia (Figure 4). Increasing probe pressure was applied, and tissue-displacement measurements were automatically obtained at 8 force increments of probe pressure (0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 kg). Computational software recorded the displacement measurements at each force increment, and these were used to generate force-displacement curves (millimeters of tissue displacement per kilogram of probe force). This use of the Myotonometer to measure muscle stiffness has been demonstrated to be valid and reliable.[29] The intrarater and interrater reliabilities were acceptable at a 0.5- to 1.75-kg force level of measurement (ICC > .8). Therefore, the displacement at 0.5 to 1.75 kg of each muscle was calculated for data analysis based on the mean of 3 trials.

Data Analysis

The data were obtained at prestretching (pre-ST), post-stretching (post-ST), and after the exercise. To assess the effects of stretching exercise on hamstrings performance, 2-way repeated ANOVA (3 experimental treatments, control [CON] vs SS+PNF vs SS+Taping; and 3 times, pre-ST, post-ST, and postexercise) was used for each outcome with an alpha level of .05. Post hoc analyses for multiple pairwise comparisons were used where appropriate, with level of significance lower than .05/6. In addition, effect-size estimates were calculated based on the method of Cohen for any differences observed. All data were analyzed using SPSS (version 11.5, SPSS Inc, Chicago, IL) and Excel (version 2003, Microsoft Corp, Seattle, WA) for statistical analyses.

Figure 4 — The Myotonometer probe used to measure muscle stiffness was applied perpendicularly to the surface of the muscle.

Results

ROM

The mean values for FROM and TROM are reported in Table 1. The analysis showed a significant 2-way interaction (time × intervention) with FROM (P = .001). Subsequently, the effects of 3 interventions were investigated separately. FROM significantly increased from pre-ST to post-ST and to the postexercise phase in SS+PNF (P < .001, effect size = 0.80 and 0.64) and SS+Taping (P = .004, effect size = 0.38 and 0.19). In both SS+PNF and SS+Taping, there was no FROM difference from post-stretching to postexercise phases (P > .05). There was no FROM difference between 3 phases in CON treatment.

For TROM, the analysis showed a significant 2-way interaction (time × intervention, P = .041). Subsequently, the effects of 3 interventions were investigated separately. TROM significantly increased from pre-ST to post-ST or to postexercise in SS+PNF (P = .001, effect size = 0.74 and 0.51) and SS+Taping (P < .001, effect size = 0.53 and 0.38). However, TROM decreased significantly (P = .02, effect size = 0.26) from post-ST to postexercise in the SS+PNF intervention. There was no TROM difference between 3 phases in the CON intervention.

PT

The mean values for PT are reported in Table 2. For PT, a significant 2-way interaction (time × intervention) was noted (P = .004). Subsequently, the effects of 3 interventions were investigated separately. PT significantly decreased from pre-ST to post-ST (–5.08 Nm, P = .04, effect size = 0.40) in the SS+PNF intervention. PT also significantly decreased from pre-ST to postexercise in both SS+PNF and CON (–14.85 Nm, P = .002, effect size = 0.87 and –14.33 Nm, P = .002, effect size = 0.88, respectively). On the other hand, PT remained unchanged from pre-ST to post-ST and to postexercise in the SS+Taping intervention (–2.94 Nm, P > .05 and –1.60 Nm, P > .05).

Muscle Stiffness

For muscle stiffness, Table 3 shows that there was no 2-way interaction (time × intervention; P > .05) and no main effect of stretch intervention (P > .05), only significant main effects for time (P < .001). On average

Table 1 First-Felt Mild Sensation of Pain Range of Motion (FROM) and Maximum Tolerable Tension Range of Motion (TROM) Before and After Stretching and Exercise, °, Mean ± SD

	Prestretching		Poststretching		Postexercise	
Treatment	FROM	TROM	FROM	TROM	FROM	TROM
Control	46.85 ± 12.87	69.18 ± 11.63	47.15 ± 12.63	69.51 ± 11.86	45.96 ± 12.00	70.18 ± 12.36
SS+PNF	47.07 ± 12.32	69.41 ± 11.26	57.48 ± 13.56*	78.89 ± 13.84*	55.19 ± 13.18*	75.48 ± 12.65*#+
SS+Taping	48.59 ± 14.05	70.85 ± 11.88	54.04 ± 14.71*	78.44 ± 16.03*	51.22 ± 13.01*#	76.63 ± 17.01*

Abbreviations: SS, static stretching; PNF, proprioceptive neuromuscular facilitation.
*Significant change in ROM compared with prestretching values.
#Significant change in ROM compared with prestretching and poststretching values.
+Significant change in ROM compared with poststretching values.

Table 2 Hamstrings Maximal Concentric Isokinetic Strength on Peak Torque at 180°/s, Mean ± SD

Treatment	Prestretching	Poststretching	Postexercise
Control	80.29 ± 11.87	80.33 ±11.35 (0.04)	65.96 ± 19.84 (–14.33)#
SS+PNF	84.15 ± 12.32	79.07 ± 13.20 (–5.08)*	69.29 ± 20.91 (–14.85)#
SS+Taping	83.41 ± 15.61	80.47 ± 12.34 (–2.94)	81.81 ± 15.33 (–1.60)

Abbreviations: SS, static stretching; PNF, proprioceptive neuromuscular facilitation.
*Significant change in mean peak torque compared with prestretching.
#Significant peak torque change compared with prestretching and poststretching values.

among the 3 stretching interventions, muscle stiffness did not significantly change from pre-ST to post-ST ($P > .005$). However, the muscle became stiffer from pre-ST to postexercise ($P < .001$, effect size = 0.4–0.49) in the 3 stretching interventions.

Discussion

The results of the current study indicate that 1 session of stretching improves hamstrings flexibility (SS+PNF: FROM = 10.41° and TROM = 9.48°; SS+Taping: FROM = 5.45° and TROM = 7.59°), and these effects are maintained after a bout of maximal isokinetic knee-flexion–extension contraction exercise, but there is a decrease in TROM from poststretching to postexercise in the SS+PNF intervention. These results were consistent with previous studies that have reported significant increases in hamstrings flexibility after a bout of stretching.[3,12] To our knowledge, however, our study is the first to demonstrate that the stretching effects were maintained after a bout of maximal isokinetic knee-flexion–extension contractions. In addition, our results support the SS+Taping intervention, which had an immediate and maintained effect on hamstrings flexibility in terms of FROM and TROM.

Increased stretch tolerance may explain the observed ROM increase in hamstrings flexibility. Several theories are proposed to explain the increase in hamstrings flexibility after stretching, including decreased muscle stiffness, increased muscle compliance,[12,24] and modified stretch sensation.[10] Previous studies found that short-term stretching exercises increased flexibility but did not decrease stiffness of the hamstrings muscle.[16,23] In agreement with previous findings, there was no change in muscle stiffness after stretching interventions in our investigation. Thus, it is likely that the reason for the “flexibility increase” in terms of the increased ROM was modified stretch sensation. This assumption is further supported by the maintained effect of FROM and TROM in SS+Taping after a bout of maximal isokinetic knee-flexion–extension contractions. Taping is believed to send tactile stimulation signals to the central nervous system, inhibiting discomfort during stretching or contractions.[21] Further study is needed to verify this assumption.

Our results also demonstrated that muscle PT decreased poststretching and postexercise compared with prestretching values in the SS+PNF intervention (–5.08 Nm and –14.85 Nm, respectively). It seems that the SS+PNF stretching exercises impair hamstrings force. This finding is also consistent with previous studies that demonstrated that stretching exercises decreased lower extremity muscle force.[4,20] Researchers have proposed that this impairment may be associated with stress relaxation; alteration in the force–velocity, length–tension relationships; or motor-unit recruitment.[4,9] Our results support these assumptions. Thus, caution should be

Table 3 Amount of Tissue Displacement by Different Forces Among 3 Treatments, Prestretching, Poststretching, and Postfatigue, Mean ± SD

Treatment	Force, kg	Prestretching	Poststretching	Postexercise
Control	0.50	7.56 ± 1.56	7.56 ± 1.56 (0.00)	7.00 ± 1.30 (–0.56)
	0.75	8.81 ± 1.57	8.83 ± 1.56 (0.02)	8.28 ± 1.40 (–0.53)
	1.00	9.87 ± 1.58	9.86 ± 1.55 (–0.01)	9.32 ± 1.47 (–0.56)
	1.25	10.63 ± 1.55	10.67 ± 1.57 (0.04)	10.06 ± 1.37 (–0.57)
	1.50	11.33 ± 1.47	11.34 ± 1.48 (0.01)	10.74 ± 1.27 (–0.59)
	1.75	11.99 ± 1.53	12.07 ± 1.49 (0.09)	11.38 ± 1.21 (–0.61)
SS+PNF	0.50	7.45 ± 1.57	7.12 ± 1.39 (–0.32)	6.85 ± 1.39 (–0.59)
	0.75	8.68 ± 1.63	8.48 ± 1.56 (–0.20)	8.14 ± 1.62 (–0.54)
	1.00	9.76 ± 1.64	9.59 ± 1.61 (–0.17)	9.21 ± 1.72 (–0.55)
	1.25	10.50 ± 1.61	10.32 ± 1.51 (–0.18)	9.90 ± 1.58 (–0.60)
	1.50	11.19 ± 1.54	11.03 ± 1.55 (–0.16)	10.62 ± 1.48 (–0.57)
	1.75	11.93 ± 1.47	11.69 ± 1.52 (–0.24)	11.28 ± 1.51 (–0.65)
SS+Taping	0.50	7.10 ± 1.59	6.81 ± 1.06 (–0.29)	6.68 ± 1.12 (–0.41)
	0.75	8.30 ± 1.66	7.92 ± 1.15 (–0.38)	7.84 ± 1.26 (–0.45)
	1.00	9.33 ± 1.73	8.92 ± 1.19 (–0.41)	8.91 ± 1.35 (–0.43)
	1.25	10.12 ± 1.70	9.71 ± 1.19 (–0.41)	9.71 ± 1.39 (–0.42)
	1.50	10.84 ± 1.62	10.43 ± 1.22 (–0.41)	10.43 ± 1.36 (–0.41)
	1.75	11.49 ± 1.62	11.20 ± 1.22 (–0.30)	11.23 ± 1.28 (–0.27)

Abbreviations: SS, static stretching; PNF, proprioceptive neuromuscular facilitation. On average among the 3 stretching treatments, the muscle stiffness did not significantly change from prestretching to poststretching phases ($P > .005$). However, the muscle became stiffer from prestretching to postexercise ($P < .001$, effect size = 0.4–0.49) among the 3 treatments.

used in prescribing SS+PNF of the hamstrings muscles if hamstrings force is a factor.

It is noteworthy that the negative effect of muscle performance did not occur in the SS+Taping intervention. The application of kinesio taping on the quadriceps has been shown to increase isokinetic muscle strength[17,19] and muscle activity.[17] Similar to this finding, decreased muscle performance was not found after the SS+Taping intervention in our results. The proposed mechanisms of taping's effect on muscle performance may have 2 aspects: sensory and mechanical alterations. In terms of sensory alterations, local excitatory interneurons of the muscle can be stimulated by the taping, resulting in an increase in muscle contraction during stretching. In terms of mechanical alterations, muscle taping was indicated to alter the length–tension relationship of muscle and optimize actin-myosin overlap to augment force generation of the muscle.[30,31] Based on our findings and proposed mechanisms, we suggest that taping is important to consider when stretching is prescribed for the hamstrings.

Limitations of the study should be noted. The subjects in this study were healthy male asymptomatic college students with limited hamstrings flexibility. Results may be different in different samples. Future study is required to determine the effectiveness of SS+Taping in individuals with symptoms that may be related to hamstrings injury. In addition, muscle performance was evaluated only by concentric contraction. Assessment of muscle performance may be different from the other outcomes such as eccentric contraction, vertical jump, running speed, and/or endurance ability. However, we evaluated only 1 test to avoid muscle fatigue or injury.

Perspectives

Researchers have shown that stretching exercises increase muscle flexibility and decrease muscle contraction.[3,5] Feedback from athletes and authors indicate that they perceive the PNF technique as contraction and kinesio taping as more tactile stimulation during muscle lengthening and thus may prevent the negative effects of the stretching technique. In the current study, both stretching protocols (SS+PNF and SS+Taping) were tested and showed significant increase in flexibility of the hamstrings, and these effects continued after a bout of maximal isokinetic knee-flexion–extension contractions. In addition, reduction in isokinetic force did not occur after SS+Taping. As the SS+Taping technique showed positive and no negative effects, the protocol can be applied in practical settings.

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