Original Article

A Randomised, Placebo-Controlled Trial of Neurodynamic Sliders on Hamstring Responses in Footballers with Hamstring Tightness

Pattanasin Areeudomwong[1,2], Ketsarakon Oatyimprai[1], Saranchana Pathumb[1]

Submitted: 15 June 2016
Accepted: 8 Aug 2016
Online: 7 Dec 2016

[1] *Department of Physical Therapy, School of Health Science, Mae Fah Luang University, Chiang Rai, Thailand 57100*

[2] *Research Center of Back, Neck, Other Joint Pain and Human Performance, Khon Kaen University, Khon Kaen, Thailand 40002*

To cite this article: Areeudomwong P, Oatyimprai K, Pathumb S. A randomised, placebo-controlled trial of neurodynamic sliders on hamstring responses in footballers with hamstring tightness. *Malays J Med Sci.* 2016;**23(6)**:60–69. http://dx.doi.org/10.21315/mjms2016.23.6.7

To link to this article: http://dx.doi.org/10.21315/mjms2016.23.6.7

Abstract

***Background*: Neurodynamics intervention is known to increase apparent muscle extensibility, but information regarding hamstring responses after a neurodynamic sliders (NS) technique is scarce. The aim of this study was to evaluate the effects of NS on apparent hamstring extensibility and activity in footballers with hamstring tightness.**

***Methods*: Forty eligible healthy male footballers with hamstring tightness were each randomly allocated to either a 4-week NS technique or a control group (CG) receiving placebo shortwave intervention. Knee extension angles were measured with the passive knee extension test, and maximal voluntary isometric contraction (MVIC) of hamstrings was measured by a surface electromyography at baseline and after intervention sessions.**

***Results*: The results showed that NS produced a statistically and clinically significant increase in knee extension angle compared to CG ($P < 0.001$); however, there was no difference between the groups receiving MVIC of hamstrings. Within group comparison, NS also provided a significant increase in knee extension angle ($P < 0.001$), whereas the control group did not. There was no change in hamstring MVIC in either group after intervention.**

***Conclusions*: The findings of this study reveal that four weeks of NS technique improved apparent hamstring extensibility but did not change the hamstring activity in footballers with hamstring tightness.**

Keywords: *flexibility, range of motion, electromyography*

Introduction

Hamstring muscles play a role in such human movements such as walking, running, and jumping (1). Limited hamstring extensibility is commonly observed in general and athletic populations (2). Although the etiology of hamstring injury is unclear, it may be due to poor hamstring extensibility (2–4). Alterations in hamstring extensibility could cause joint dysfunction and have been related to orthopaedic disorders, such as low back pain (5) and patellofemoral joint syndrome (6). Therefore, maintaining normal joint range of motion (ROM), which may occur through hamstring stretching, may reduce the risk of orthopaedic disorders (7, 8).

Although abnormal muscle and tendon stiffness has been thought to be a cause of poor hamstring extensibility, several authors emphasised that abnormal mechanosensitivity due to sciatic nerve adhesion could potentially result in decreased hamstring extensibility and stretch tolerance (9, 10). Healthy individuals (9) and individuals with hamstring strain (11) who presented with abnormal mechanosensitivity had poor hamstring extensibility. Neurodynamic sliders (NS) technique is a method of producing a sliding movement of neural structures relative to their mechanical interfaces. This technique provides tension on the targeted nerve structure proximally via joint movements while releasing tension of the nerve distally, and then reversing the sequence (12). The effectiveness of NS has been proposed to improve measures of apparent hamstring extensibility (9–11, 13) and postural balance (14). Weppler and Magnusson (15) suggested that increased joint ROM after a short stretching session may be due to changes in an individual's tolerance of the stretch rather than changes in musculotendinous structures. Moreover, it is believed that the strong afferent input from the acute stretch may reduce firing rates of mechanoreceptors and proprioceptors that may also affect sensory adaptation (16). Furthermore, NS may provide more excursions of the neural structures or may decrease neural mechanosensitivity (17). In addition, NS may induce sliding of the sciatic nerve at the thigh relative to its nerve beds by performing joint movements that elongate the nerve beds and fascial system, including the hamstring muscles (18–20). This may allow increased joint ROM.

Although numerous researchers have suggested an increase in apparent hamstring extensibility after a single bout of NS technique (10, 13, 14), no studies have reported improvement in apparent hamstring extensibility after a short course of NS in footballers with hamstring tightness. Previous studies have demonstrated that rapid cyclic stretches reduced EMG amplitude caused by neural inhibition (21, 22). However, the effect of NS on hamstring activity is still unknown. Therefore, the aim of the present study was to examine the effects of four weeks of NS on measures of apparent hamstring extensibility and maximal voluntary isometric contraction (MVIC) in footballers with hamstring tightness. We hypothesised that a 4-week NS would improve the apparent extensibility without changing MVIC of the hamstrings.

Materials/Participants and Methods

Study Design

The present study was a randomised assessor-blind, placebo-controlled trial with pre- and post-assessments, conducted in the Physical Therapy Laboratory at Mae Fah Luang University, Thailand. It was approved by the Ethic Committee for Human Research at Mae Fah Luang University, based on the Declaration of Helsinki.

Participants

Sample size was estimated using a formula of analysis of variance (ANOVA) on the basis of knee extension angle and assuming 5% significance, and 90% power. The total sample size was 20 participants.

Forty male footballers between 18 and 25 years of age were recruited from Mae Fah Luang University Football Club, Chiang Rai province, Thailand. Inclusion criteria were hamstring tightness of the dominant leg, defined as a knee-extension angle of more than 15 degrees; measured by passive knee extension (PKE) test (23); presenting positive signs from the slump test, which is used to help differentiate between apparent hamstring tightness due to neural mechanosensitivity and other causes (24, 25); and having been actively participating in football for at least four hours/week for at least three days/week. Subjects were excluded by a medical doctor if they had musculoskeletal or neurological disorders, systemic diseases, active hip or knee injury, or inflammation. All participants provided a written informed consent before participation.

Outcome Measures

All outcome measures were collected by an assessor who was blinded to the participants' group randomisation. All participants were asked to attend a common assessment session to avoid guessing by the assessor, and they did not reveal the treatment they received. Before the testing period, all participants were familiarised with the test procedures. The primary outcome measure was the PKE test, which is reliable and widely used to evaluate changes in hamstring flexibility (23). In our test, the participant lay supine with the nondominant leg in 0° of hip flexion, fixed with a Velcro strap secured to the couch. The lumbopelvic region was also maintained in the neutral position using a Velcro strap. The dominant leg, which was defined as the preferred kicking leg, was in 90° flexion at the hip and the knee. The thigh was kept in position by being strapped to a fixed horizontal bar, and the lower leg was supported by the assessor's hand. The angle of knee extension was measured with a universal goniometer whose axis was placed on the lateral epicondyle of the femur, the stationary arm parallel to the thigh, and the movable arm parallel to the lower leg. The assessor gradually extended the knee passively until the participant reported a strong but tolerable stretching sensation in the hamstring muscles. The average value of three tests was used. A lesser angle of knee extension represented greater apparent hamstring extensibility.

To evaluate the MVIC of the hamstrings of the dominant leg, which was a secondary outcome measure, a manual sphygmomanometer and a surface electromyography (sEMG) were used. The participant lay supine with hips and knees flexed to 90° and heels resting on an adjusted table. The cuff of the manual sphygmomanometer (HM-1100, Hico Medical Co. Ltd., Japan) was inflated to 10 mmHg and placed under the heel of the dominant leg. The sEMG was used to measure hamstring activity. A pair of active adhesive disposable Ag/AgCl disc surface electrodes (EL 503, BIOPAC Systems, California, USA) were then positioned on the midpoint of a line connecting between the ischial tuberosity and the medial tibial epicondyle (26). The sEMG setting has been described previously (27). The participants were asked to push the heel into the cuff as hard as possible without pelvic lifting off the couch for 5-second holds while sEMG simultaneously recorded the root mean square (RMS) values of the biceps femoris muscle. A 2-minute rest period was provided between the tests to prevent muscle fatigue (28). The middle three seconds of the RMS value from 5-second period testing were analysed, and the average value of three tests was used.

To minimise the diurnal variation of hamstring flexibility and MVIC, all measurements were performed at the same time of the day.

Procedures

Before data collection, the reliability coefficient of the measurement of the PKE and MVIC tests of the biceps femoris muscle of the dominant leg was determined by the assessor involved in the real study using the procedures just described. Ten healthy male footballers who were not involved in the present study participated in a reliability trial. The knee extension angle in the PKE test and the MVIC test was measured twice within a 3-day interval. Intraclass correlation coefficients were calculated from the results of subsequent measurements. Results of intra-rater reliability tests revealed high reliability (ICC = 0.93; 95% confidence interval, CI = 0.75–0.98, $P < 0.001$ for PKE test, and ICC = 0.90; 95% CI = 0.72–0.97, $P < 0.001$ for MVIC test).

The participants were tested for all outcome measurements before randomisation for baseline values and at one day after the last intervention session for post-test values. A block randomisation with a block size of two was performed. The participants were randomly allocated to either a 4-week NS group or a control group (CG). Sealed opaque envelopes were used for the purpose of concealed allocation. The research assistant, who was not aware of the treatment process, performed the randomisation process.

The NS group received the NS technique on the sciatic nerve of the dominant leg, as suggested by Castellote-Caballero et al. (9). The purpose of NS is to produce a sliding movement of neural structures relative to their mechanical interfaces with stressing to the neural structure proximally while releasing stress distally and then reversing the sequence. This technique started with a sitting-on-chair position, thoracic slump, both hands clasped posteriorly at lumbosacral level, feet unsupported, off the floor, followed by two alternating sets of movements of (i) cervical flexion, knee flexion, and ankle plantar flexion, and (ii) cervical extension, knee extension, and ankle dorsiflexion (Figure 1). Active alternation between (i) and (ii) were performed for 60-second time periods and repeated five times. The NS group received three sessions of treatment per week for four weeks, supervised throughout by one of the researchers who was clinically experienced in the NS technique.

The CG received placebo pulse shortwave (PSW) for 10 minutes. The PSW device was turned on without any electrical current being applied. Placebo sessions were given three times a week for four weeks.

All participants were asked to avoid other drugs, alternative treatments, or hamstring stretching during the study periods. The participants were also instructed to record any adverse effects of intervention and lower-limb injury throughout the study.

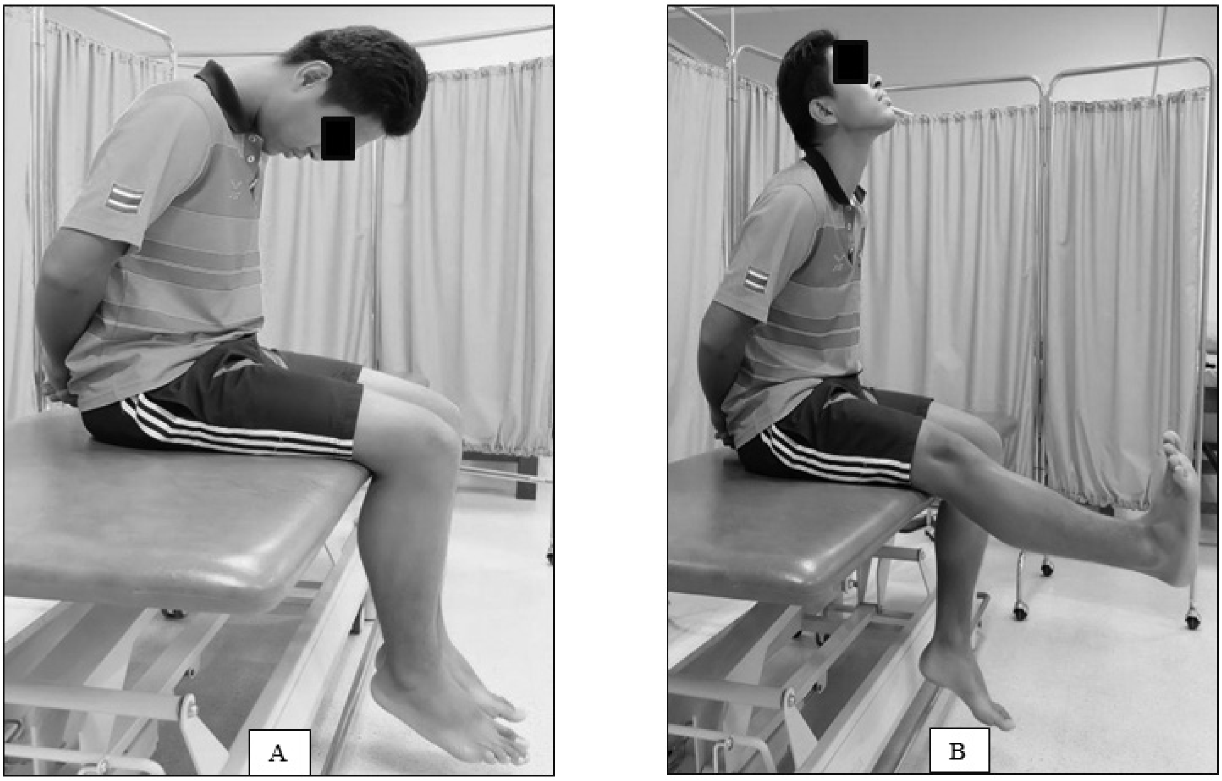

Figure 1. The neurodynamic sliders used in the present study. The participants sat in high sitting position with hand placed behind the neck and thoracic slump. They started with cervical flexion with knee flexion and ankle plantarflexion (A), and then moved into cervical extension with knee extension and ankle dorsiflexion (B). Participants did these alternating active movements for 60 seconds and five repetitions.

Statistical Analyses

Descriptive statistics (mean, standard deviations, and 95% CI) were calculated for values of baseline and one day after the last intervention session. SPSS version 16.0 (IBM Corporation, Armonk, NY, USA) was used for data analyses. The Kolmogorov-Smirnov test revealed that all outcome data were normally distributed; therefore, parametric testing was used for data analyses. One-way repeated measures ANOVA was used to compare the baseline and post-test values of each outcome measure. One-way ANOVA was used to compare the change values of outcome measures between the groups. The Bonferroni post-hoc test was used for multiple comparisons. The level of significance was set at $P < 0.05$.

Results

Out of 51 participants recruited for this study, a total of 40 eligible participants consented to participate. Reasons for excluding the participants are demonstrated in Figure 2. Characteristics of the participants are shown in Table 1. There were no significant differences between the groups at the start of the study. None of the participants reported any adverse effects or lower-limb injury over the study period.

One-way repeated measures ANOVA determined a statistically significant difference of knee extension angle between time points ($F_{(1,19)} = 26.29$; $P < 0.001$). Post-hoc tests revealed the improvement in knee extension angle after receiving four weeks of NS technique ($P < 0.001$). In contrast, there was no significant difference between time points in the control group ($F_{(1,19)} = 3.12$; $P = 0.11$). The MVIC of hamstrings did not differ from the baseline value of the NS group ($F_{(1,19)} = 0.51$; $P = 0.50$) and the control group ($F_{(1,19)} = 0.03$; $P = 0.86$) (Table 2).

One-way ANOVA revealed a statistically significant difference of change values of the knee extension angle between the groups ($F_{(1,38)} = 18.24$; $P < 0.001$). A post-hoc test demonstrated a statistically and clinically greater improvement in the knee extension

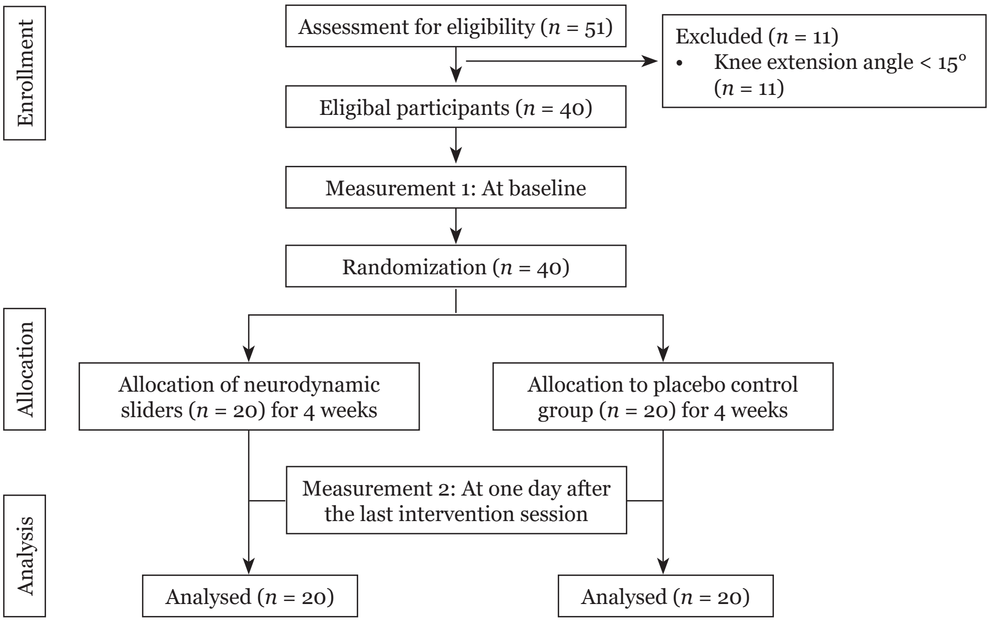

Figure 2. Flow of participants

Table 1. Characteristics of the participants

	Neurodynamic sliders group (*n* = 20)	Control group (*n* = 20)	*P*-value[a]
Age (years), mean (SD)	19.82 (1.40)	20.09 (1.14)	0.92
Weight (kg), mean (SD)	69.45 (19.35)	63.36 (7.81)	0.63
Height (cm), mean (SD)	174.09 (4.76)	171.36 (4.30)	0.71
Knee extension angle (degrees), mean (SD)	23.58 (3.78)	24.83 (2.76)	0.94
Maximal voluntary isometric contraction of hamstring muscle (millivolts) , mean (SD)	0.16 (0.11)	0.19 (0.10)	0.44

Note: [a]Independent *t*-test ($P < 0.05$).

angle for the NS group than for the control group (mean change difference = 10.500 ± 2.458; $P < 0.001$). There was no significant difference of MIVC between the groups ($F_{(1,38)} = 0.51$; $P = 0.48$) (Table 2). None of the participants in either group reported the use of other treatments or adverse effects after receiving interventions.

Discussion

This study demonstrated that a 4-week NS technique improved knee extension angle, which reflected apparent hamstring extensibility without causing any significant changes in the hamstring activity in footballers with hamstring tightness. Brosseau et al. (30) suggested that the change of at least 5° in knee ROM was necessary to exceed measurement error. The within-group (mean difference = 11.917 ± 8.051°) and between-group (mean change difference = 10.500 ± 2.458°) differences of the knee extension angle in the NS group exceeded the measurement error. The NS intervention also provided a clinically greater improvement in knee ROM based on 10° difference as being a clinically meaningful difference (30) compared to the control group; therefore, NS can provide clinically meaningful ROM changes that are not due to measurement errors.

Mendez-Sanchez et al. (10) conducted a randomised controlled pilot trial to evaluate the immediate effects of adding NS of the sciatic nerve to static hamstring stretching on hamstring flexibility measured by passive straight leg raise (SLR) in eight healthy male soccer players. They reported a greater improved ROM of passive SLR in the group of NS of the sciatic nerve plus hamstring static stretching

Table 2. Results of mean difference within group and mean change difference between groups of knee extension angle and maximal voluntary isometric contraction (MVIC) of hamstring muscle.

Outcome	Group				Difference within group (95% CI)		Difference between groups (95% CI)
	Baseline		One day after the last intervention session				
	Neurodynamic sliders	Control	Neurodynamic sliders	Control	Neurodynamic sliders	Control	
Knee extension angle (degrees)	23.580 ± 3.777	24.830 ± 2.758	11.670 ± 6.814	23.420 ± 2.610	11.917 ± 8.051[a] (6.082 to 17.032)	1.417 ± 2.778 (-0.349 to 3.182)	10.500 ± 2.458[b] (5.212 to 15.788)
MVIC of hamstring muscle (millivolts)	0.161 ± 0.111	0.188 ± 0.095	0.189 ± 0.098	0.185 ± 0.098	-0.028 ± 0.140 (-0.117 to 0.061)	0.003 ± 0.054 (-0.031 to 0.037)	-0.031 ± 0.043 (-0.124 to 0.062)

Note: [a]One-way repeated measures analysis of variance (ANOVA) ($P < 0.001$), [b]One-way ANOVA ($P < 0.001$).

compared to hamstring static stretching alone. Castellote-Caballero et al. (9) compared the short-term effects of NS to no intervention control on hamstring flexibility using a passive SLR test in healthy male soccer players. The authors showed that NS provided a significant improvement in ROM of passive SLR. Park et al. (14) applied NS of the sciatic nerve on hamstring flexibility and postural balance in healthy adults. They reported that NS of the sciatic nerve exhibited an immediate improvement in hamstring flexibility and postural balance of healthy adults. These findings (9–10, 14) were consistent with the result of the present study. The previous studies used the passive SLR test rather than the PKE test. We chose PKE test over the SLR test to evaluate hamstring extensibility in line with the recommendation of Davis et al. (32) that the PKE test was of high validity and reliability in determining hamstring muscle extensibility, which has been used in the present study. In addition, PKE could minimise the compensatory pelvic rotation during testing. Thus, PKE may reflect the accurate change of apparent hamstring extensibility after intervention.

There were three proposed mechanisms to explain the greater knee extension angle after NS. First, increased knee extension angle may be due to changes in the individual's tolerance of the stretch (15), and the strong afferent input from the acute stretch may reduce firing rates of mechanoreceptors and proprioceptors that may also affect sensory adaptation and allow increased joint ROM (16). Second, NS may provide more excursions of the neural structures at the vertebral canal, the buttock, and especially the sciatic nerve in the posterior thigh. It may also decrease the neural mechanosensitivity that may play a factor in determining an increase in apparent hamstring extensibility (17). Third, NS may induce sliding of the sciatic nerve at the thigh relative to its nerve beds by performing joint movements that elongate the nerve beds and the fascial system, including the hamstring muscles (18–20). This may allow increased joint ROM. Although several studies supported an increase in apparent hamstring extensibility after receiving the NS technique (9–10, 13–14), we do not know whether the change in viscoelasticity of the hamstring muscle could influence an increase in hamstring extensibility.

The present study revealed that there was no significant reduction in MVIC of the hamstrings. Although the mechanism of the NS technique on muscle activity is unclear, an unchanged MVIC of this study might be because the NS only modified sensory perception or an individual's tolerance of the stretch (15, 32), and NS did not affect the motor unit action potential of the sciatic nerve, which activates hamstring activity. The result of the present study was in agreement with Yuktasir and Kaya (34), who reported no change of jump performance after receiving either six weeks of static or six weeks of PNF stretching exercise. However, different stretching intervention and outcome measures between the present study and the study of Yuktasir and Kaya (34) makes it difficult to compare the results. More research studies are needed to clarify the long-term effects of NS intervention on muscle activity and to determine how this affects the choice of intervention in sports.

There are some limitations of this study. First of all, only healthy young male footballers were recruited to this study; therefore, the findings may not be applied in other populations, such as female or older footballers. Second, it is not known if an appropriate dosage and repetition of NS intervention might provide a greater intervention effect; therefore, the standardised protocol for NS intervention should be further studied. Third, it is unknown how long the effects of an increase in apparent hamstring extensibility lasted after receiving NS. Fourth, this study used only the PKE test and the MVIC test of hamstrings. Future studies should evaluate the effectiveness of the NS technique using pain tolerance and nerve excursion to fulfill other effects of this technique. Finally, the angle of the PKE test was recorded when the participant reported a strong but tolerable stretching sensation. Quantifying the level of stretching sensation among the participants, however, may not be accurate. Future studies should use other accurate outcomes to measure stretching sensation, such as the visual analogue scale or the numerical rating scale.

Conclusion

The present study revealed that a 4-week NS technique provides an increase in knee extension angle, representing increased apparent hamstring extensibility and no change of meaningful EMG activity of the hamstring muscle in healthy male footballers with hamstring tightness. It indicates that extensibility or restoration of the natural movement of neural structures and surrounding mechanical interfaces can contribute to decreased muscle tightness.

Acknowledgement

The authors would like to thank the participants for their good cooperation. Also, the authors are grateful to Dr. Mitra Cassely for proofreading.

Conflict of interest

None

Funds

None

Authors' Contribution

Conception and design: PA
Analysis and interpretation of the data: PA
Drafting of the article: PA
Final approval of the article: PA, KO, SP
Provision of study materials or patients: F
Collection and assembly of data: KO, SP

Correspondence

Dr. Pattanasin Areeudomwong
PhD of Human Movement Sciences (Khon Kaen University, Thailand)
Department of Physical Therapy,
School of Health Science,
Mae Fah Luang University,
Chiang Rai, Thailand 57100
Tel: +6687 573 7852
E-mail: pattanasin.are@mfu.ac.th

References

1. Lumbroso D, Ziv E, Vered E, Kalichman L. The effect of kinesio tape application on hamstring and gastrocnemius muscles in healthy young adults. *J Bodyw Mov Ther*. 2014;**18(1)**:130–138. http://dx.doi.org/10.1016/j.jbmt.2013.09.011.

2. Witvrouw E, Danneels L, Asselman P, D'Have T, Canbier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players: a prospective study. *Am J Sports Med*. 2003;**31(1)**:41–46. http://dx.doi.org/10.1177/03635465030310011801.

3. Henderson G, Barnes CA, Portas MD. Factors associated with increased propensity for hamstring injury in English Premier League soccer players. *J Sci Med Sport*. 2010;**13(4)**:397–402. http://dx.doi.org/10.1016/j.jsams.2009.08.003.

4. Bradley PS, Portas MD. The relationship between preseason range of motion and muscle strain injury in elite soccer players. *J Strength Cond Res*. 2007;**21(4)**:1155–1159. http://dx.doi.org/10.1519/R-20416.1

5. Tafazzoli F, Lamontagne M. Mechanical behavior of hamstring muscles in low-back pain patients and control subjects. *Clin Biomech*. 1996;**11(1)**:16–24. http://dx.doi.org/10.1016/0268-0033(95)00038-0.

6. Petersen W, Ellermann A, Gösele-Koppenburg A, Best R, Rembitzki IV, Brüggemann GP, et al. Patellofemoral pain syndrome. *Knee Surg Sports Traumatol Arthrosc*. 2014;**22(10)**:2264–2274. http://dx.doi.org/10.1007/s00167-013-2759-6.

7. Decoster LC, Cleland J, Altieri C, Russell P. The effects of hamstring stretching on range of motion: A systematic literature review. *J Orthop Sports Phys Ther*. 2005;**35(6)**:377–387. http://dx.doi.org/10.2519/jospt.2005.35.6.377.

8. Hartig DE, Henderson JM. Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *Am J Sports Med*. 1999;**27(2)**:173–176. http://dx.doi.org/10.1177/03635465990270021001.

9. Castellote-Caballero Y, Valenza MC, Martin-Martin L, Cabrera-Martos I, Puentedura E, Fernandez-de-las-Penas C. Effects of a neurodynamic sliding technique on hamstring flexibility in healthy male soccer players: A pilot study. *Phys Ther Sport*. 2013;**14(3)**:156–162. http://dx.doi.org/10.1016/j.ptsp.2012.07.004.

10. Mendez-Sanchez R, Alburquerque-Sendin F, Fernandez-de-las-Penas C, Barbero-Iglesias FJ, Sanchez-Sanchez C, Calvo-Arenillas, JI, et al. Immediate effects of adding a sciatic nerve slider technique on lumbar and lower quadrant mobility in soccer players: a pilot study. *J Altern Complement Med*. 2010;**16(6)**:669–675. http://dx.doi.org/10.1089/acm.2009.0403.

11. Turl SE, George KP. Adverse neural tension: a factor in repetitive hamstring strain? *J Orthop Sports Phys Ther*. 1998;**27(1)**:16–21. http://dx.doi.org/10.2519/jospt.1998.27.1.16.

12. Shacklock M. *Clinical neurodynamics: A new system of musculoskeletal treatment*. London, UK: Elsevier Health Sciences; 2005.

13. Castellote-Caballero Y, Valenza MC, Puentedura E, Fernandez-de-las-Penas C, Alburquerque-Sendin F. Immediate effects of neurodynamic sliding versus muscle stretching on hamstring flexibility in subjects with short hamstring syndrome. *J Sports Med*. 2014:1–8. http://dx.doi.org/10.1155/2014/127471.

14. Park J, Cha J, Kim H, Asakawa Y. Immediate effects of a neurodynamic sciatic nerve sliding technique on hamstring flexibility and postural balance in healthy adults. *J Phys Ther Rehabil Sci*. 2014;**3(1)**:38–42.

15. Weppler CH, Magnusson SP. Increasing muscle extensibility: A matter of increasing length or modifying sensation? *Phys Ther*. 2010;**90(3)**:438–449. http://dx.doi.org/10.2522/ptj.20090012.

16. Björklund M, Hamberg J, Crenshaw AG. Sensory adaptation after a 2-week stretching regimen of the rectus femoris muscle. *Arch Phys Med Rehabil*. 2001;**82(9)**:1245–1250. http://dx.doi.org/10.1053/apmr.2001.24224.

17. Ellis RF, Hing WA, McNair PJ. Comparison of longitudinal sciatic nerve movement with different mobilization exercises: an in vivo study utilizing ultrasound imaging. *J Orthop Sports Phys Ther*. 2012;**42(8)**:667–675. http://dx.doi.org/10.2519/jospt.2012.3854.

18. Coppieters MW, Kurz K, Mortensen TE, Richards NL, Skaret IA, McLaughlin LM, et al. The impact of neurodynamic testing on the perception of experimentally induced muscle pain. *Man Ther*. 2005;**10(1)**:52–60. http://dx.doi.org/10.1016/j.math.2004.07.007.

19. Coppieters MW, Alshami AM, Babri AS, Souvlis T, Kippers V, Hodges PW. Strain and excursion of the sciatic, tibial, and plantar nerves during a modified straight leg raising test. *J Orthop Res*. 2006;**24(9)**:1883–1889.

20. Coppieters MW, Butler DS. Do 'sliders' slide and 'tensioners' tension? An analysis of neurodynamic techniques and considerations regarding their application. *Man Ther*. 2008;**13(3)**:213–221. http://dx.doi.org/10.1016/j.math.2006.12.008.

21. Avela J, Kyröläinen H, Komi PV. Altered reflex sensitivity after repeated and prolonged passive muscle stretching. *J Appl Physiol*. 1999;**86(4)**:1283–1291.

22. Avela J, Finni T, Liikavainio T, Niemala E, Komi PV. Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. *J Appl Physiol*. 2004;**96(6)**:2325–2332.

23. Bakhtiary AH, Fatemi E, Khalili MA, Ghorbani R. Localised application of vibration improves passive knee extension in women with apparent reduced hamstring extensibility: a randomized trial. *J Physiotherapy*. 2011;**57(3)**:165–171. http://dx.doi.org/10.1016/S1836-9553(11)70037-6.

24. Lew PC, Briggs CA. Relationship between the cervical component of the slump test and change in hamstring muscle tension. *Man Ther*. 1997;**2(2)**:98–105. http://dx.doi.org/10.1054/math.1997.0291.

25. Kuilart KE, Woollam M, Barling E, Lucas N. The active knee extension test and Slump test in subjects with perceived hamstring tightness. *Int J Osteopathic Med*. 2005;**8(3)**:89–97. http://dx.doi.org/10.1016/j.ijosm.2005.07.004.

26. Schache AG, Tim WD, Peter DB, Brown NA, Marcus GP. Mechanics of the human hamstring muscles during sprinting. *Med Sci Sports Exerc*. 2012;**44(4)**:647–658. http://dx.doi.org/10.1249/MSS.0b013e318236a3d2.

27. Hermans HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;**10(5)**:361–374. http://dx.doi.org/10.1016/S1050-6411(00)00027-4.

28. Ng JK, Richardson CA, Parniapour M, Kippers V. EMG activity of trunk muscles and torque output during isometric axial rotation exertion: a comparison between back pain patients and matched controls. *J Orthop Res*. 2002;**20(1)**:112–121. http://dx.doi.org/10.1016/S0736-0266(01)00067-5.

29. Brosseau L, Tousignant M, Budd J, Chartier N, Duciaume L, Plamondon S, et al. Intratester and intertester reliability and criterion validity of the parallelogram and universal goniometers for active knee flexion in healthy subjects. *Physiother Res Int*. 1997;**2(3)**:150–166. http://dx.doi.org/10.1002/pri.97.

30. De Weijer VC, Gorniak GC, Shamus E. The effect of static stretch and warm-up exercise on hamstring length over the course of 24 hours. *J Orthop Sports Phys Ther*. 2003;**33(12)**:727–33. http://dx.doi.org/10.2519/jospt.2003.33.12.727.

31. Davis DS, Quinn RO, Whiteman CT, Williams JD, Young CR. Concurrent validity of four clinical tests used to measure hamstring flexibility. *J Strength Con Res*. 2008;**22(2)**:583–588. http://dx.doi.org/10.1519/JSC.0b013e31816359f2.

32. McHugh MP, Johnson CD, Morrison RH. The role of neural tension in hamstring flexibility. *Scand J Med Sci Sports*. 2012;**22(2)**:164–169. http://dx.doi.org/10.1111/j.1600-0838.2010.01180.x.

33. Yuktasir B, Kaya F. Investigating into long-term effects of static and PNF stretching exercises on range of motion and jump performance. *J Bodyw Mov Ther*. 2009;**13(1)**:11–21. http://dx.doi.org/10.1016/j.jbmt.2007.10.001.