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ORIGINAL RESEARCH

DYNAMIC OSCILLATORY STRETCHING EFFICACY ON HAMSTRING EXTENSIBILITY AND STRETCH TOLERANCE: A RANDOMIZED CONTROLLED TRIAL

Arie Michaeli, MSc PT, MCMT[1]
Jason Cameron Tee, PhD[2]
Aimee Stewart, PhD[3]

ABSTRACT

Background: While static stretch (SS), proprioceptive neuromuscular facilitation (PNF) and oscillatory physiological mobilization techniques are documented to have positive effects on a range of motion (ROM), there are no reports on the effect of dynamic oscillatory stretching (DOS), a technique that combines these three techniques, on hamstring extensibility.

Purpose: To determine whether DOS improves hamstring extensibility and stretch tolerance to a greater degree than SS in asymptomatic young participants.

Study Design: Randomized Controlled Trial.

Methods: Sixty participants (47 females, 13 males, mean age 22 ± 1 years, height 166 ± 6 centimeters, body mass 67.6 ± 9.7 kg) completed a passive straight leg (SLR) to establish hamstring extensibility and stretch tolerance as perceived by participants, using a visual analogue scale (VAS). Participants were randomly assigned to one of two treatment groups (SS or DOS) or a placebo control (20 per group). Tests were repeated immediately following and one hour after each intervention. Data were assessed using a two-way repeated measure analysis of variance (ANOVA) and *Tukey's post hoc* test.

Results: Immediately post-intervention, there was a significant improvement in the hamstring extensibility as measured by the SLR in both the SS and DOS groups, with the DOS group exhibiting a significantly greater increase than the SS group (Control 73 ± 12°, SS 86 ± 8°, DOS 94 ± 11°, $p < 0.001$). One hour post-intervention, hamstring extensibility in the DOS group remained elevated, while the SS group no longer differed from the control group (Control 73 ± 12°, SS 80 ± 8°, DOS 89 ± 12°, $p = 0.001$). Furthermore, the stretch tolerance remained significantly elevated for the SS group, but there was no difference between the control and DOS groups, (Control 4.6 ± 1.3, SS 5.9 ± 0.8, DOS 4.3 ± 1.0 AU, $p < 0.001$).

Conclusion: DOS was more effective than SS at achieving an immediate increase in hamstring extensibility, and DOS demonstrated an increased stretch tolerance one-hour post-intervention.

Level of evidence: 2C

Keywords: Dynamic oscillatory stretching, hamstring extensibility, stretch tolerance.

[1] 1.Private Practice, Johannesburg, South Africa
[2] Leeds Beckett University, UK
[3] University of the Witwatersrand, Johannesburg, South Africa, Aimee.Stewart@wits.ac.za

CORRESPONDING AUTHOR
Arie Michaeli, MSc PT, MCMT
Clinical Solutions
32 Boundary Road, Rouxville,
Johannesburg, 2192
South Africa
Tel: (+27) 11 640 2097
Fax: (+27) 86 513 1891
E-mail: ari@clinisol.co.za

INTRODUCTION

Reduction in the extensibility of the hamstring muscles has been reported to be associated with the occurrence of back pain,[1] sacroiliac joint disorders,[2] hamstring strain,[3] patellofemoral pain syndrome,[4] and patellar tendinopathy.[5] Thus, extensibility of the hamstrings is important for optimal joint and muscle function. The extent to which muscles contract has been shown to be dependent on muscle length, and shortened or lengthened muscles may not develop maximum tension if their resting length has changed.[6] The physiological mechanisms behind the changes in muscle extensibility are debatable. Viscoelastic, reflex muscle relaxation, and stretch tolerance changes[7] have been extensively studied and are widely regarded as contributing to short- and medium-term alterations in muscle extensibility. More recently, there has been increasing attention being paid to Neurodynamics.[8] Of these four mechanisms, the scientific literature mostly cites stretch tolerance for producing short- and medium-term alterations.[7,9,10] Increased stretch tolerance means that stretching intervention enables individuals to tolerate higher levels of stretch discomfort rather than reflecting an actual change in the passive mechanical properties of tissue. In a well-designed study involving 60 healthy individuals, Ben and Harvey[9] showed that static stretching did not induce any lasting changes in muscle extensibility. Rather, it merely improved participants' tolerance for the discomfort associated with stretch, although it was not possible to ascertain the underlying physiological mechanism responsible for the improved stretch tolerance. The authors postulated that stretching has an influence on some characteristics of the sensory neural pathways stimulating muscle and joint mechanoreceptors, and this may reduce the sensation of pain.[9]

Static stretch (SS) is commonly utilized to increase range of motion (ROM), to improve performance, to prevent or reduce injury risk, and to reduce delayed onset muscle soreness.[11] However, research consistently shows that apart from improving extensibility, SS is largely ineffective in achieving the above-mentioned outcomes.[11,12] The current study introduces a novel stretching technique – dynamic oscillatory stretching (DOS). DOS is a modified proprioceptive neuromuscular facilitation (PNF) technique. DOS is similar to agonist contract-relax (ACR),[7] in that the agonist produces the stretching force on the opposite muscle (antagonist.) In this study the quadriceps femoris muscle, when attempting to stretch the hamstrings, is contracted to actively move the lower extremity into increased ROM utilizing the reciprocal inhibition mechanism.[7,13] In addition, DOS incorporates as a modification a two-second oscillatory manual stretch at the end of the range, which is applied by the therapist to assist the agonist.[15] DOS therefore consists of dynamic, oscillatory and passive stretching components. In several studies, dynamic stretches, including ACR, have been shown to be superior to SS in achieving greater ROM as well as improving the function of the antagonist muscles.[7,14] The oscillatory component of DOS resembles oscillatory physiological mobilization as described by an Maitland,[16] for the treatment of musculoskeletal disorders. Mobilization techniques have consistently been shown to be clinically effective in improving peripheral and spinal joint mobility.[17,18] It is therefore postulated that DOS is a potentially superior technique to SS in improving ROM as it incorporates three evidence-based modalities (PNF, oscillatory passive physiological mobilization and SS), all of which have been clinically proven to increase ROM.[11,13,14]

To date, no reports have been found in the literature describing the effectiveness of DOS on hamstring extensibility and stretch tolerance. The purpose of this study was to compare the effects of static and dynamic oscillatory hamstring stretching on SLR, which is a measurement of hamstring extensibility. The study also used a visual analog scale to measure the most intense perception of pain as a proxy measurement at the point of greatest stretch tolerance, immediately and one hour after the performance of SS and DOS techniques in asymptomatic young adults.

The research hypotheses were that hamstring extensibility would be affected more by DOS than SS, and that DOS would affect the self-reported perception of pain at the limit of the SLR.

METHOD

Design

The study was a randomized controlled trial with blinded outcome assessment. Treatment could not be blinded to the investigator or the subjects. Random number sequencing was generated using the Research Randomizer Computer Program by an independent investigator on the research team. The numbers were placed into individually sealed opaque envelopes, which were handed to participants after they had each undergone their baseline assessment. Participants were then randomly assigned to one of three treatment groups: SS, DOS, or control. The dependent variables were the degree of SLR ROM, and the subjects' perceived pain. The independent variables were time (pre-, immediately post, and one-hour post); and the three types of intervention: SS, DOS, and control. Sample size estimation was performed *a priori*, and determined that a sample size of nineteen participants per group would detect a clinically important difference of 5° in SLR ROM with the power of 90% and $\alpha = 0.05$.

Participants

Sixty-nine healthy young physiotherapy students recruited from a local university volunteered to participate in the study. Participants were excluded if they had a previous history of lower-extremity and/or back pathology, and/or direct injury to the hamstring muscles in the previous six months; if they suffered from a neurological disorder; if they participated in a regular stretching regimen of the hamstring muscles group; or if they attended regular yoga classes. Volunteers were eligible for the study if their hamstring extensibility, as measured by SLR ROM, was less than or equal to 90° of hip flexion. In accordance with other studies which excluded participants with flexibility greater than 90°,[19,20] nine participants with hamstring extensibility greater than 90° were excluded from this study, leaving 60 participants (47 females and 13 male) (Figure 1).

Outcome measures

Primary outcome: Measurements of hamstring extensibility performed with hip flexion and the knee in extension is referred to as the passive SLR test, which also reflects tension of the hip joint capsule[21] and/or neural tissues.[8] The SLR test demonstrates accepted inter-observer reliability (ICC 0.93 to 0.97).[22] The measurements of SLR were performed by a research assistant, an experienced physical therapist, who was not present during the stretching treatment of each participant. Her within-session intra-rater reliability was previously determined as ICC = 0.89, with the Standard Error of Measurement < 1°.

The SLR measurement position was the same as the starting position of each stretching protocol. A hand-held inclinometer that measures in two degree increments (Isomed, US Neurologicals LLC, Washington, USA) was used to measure SLR ROM. The proximal peg of the inclinometer was placed on the tibial tuberosity with the second peg parallel to the shaft of the tibia (Figure 2). The reliability of this measurement tool for SLR is ICC = 0.95 to 0.98.[23] The authors adapted the Maitland-style movement

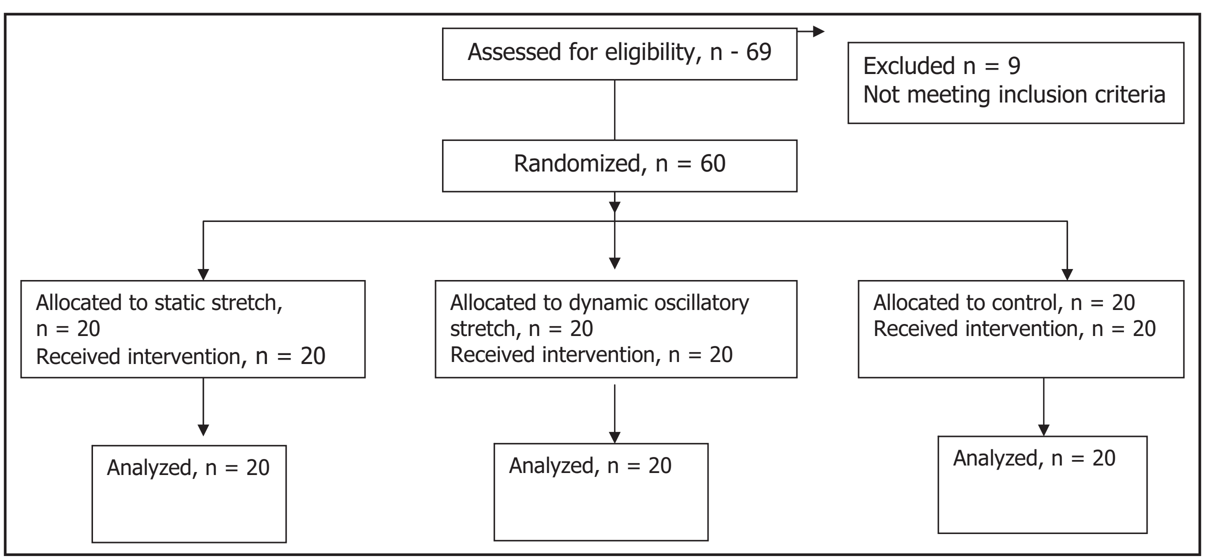

Figure 1. *Flow diagram for recruitment, follow-up and analysis*

Figure 2. *Positioning of the Inclinometer for the measurement of straight leg raise test*

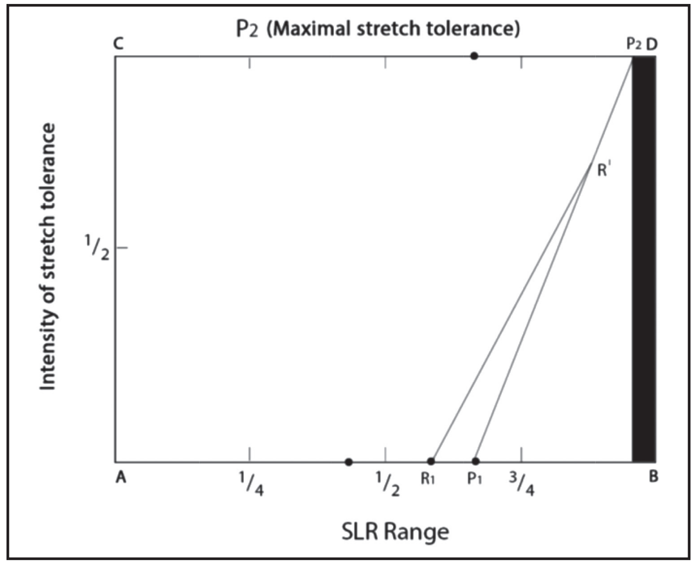

Figure 3. *The lower extremity was passively raised from the point of onset of resistance (R1) to the point of highest stretch tolerance as subjectively reported by the participant (P2). P2 was the limiting factor of the SLR. While resistance had appeared earlier in the stretch range, this was not the limiting factor (R|).*
AB represents normal range of motion of SLR.
R| is defined as increased resistance but not the limiting factor of SLR.
AC represents the intensity of perceived stretch tolerance.
BD is the end of SLR range (hamstring extensibility) and it is a broad, shaded area as the end of the range is not a distinct point.

diagram[16] to quantify end-of-range stretch tolerance. Pain onset was defined as P1; maximal pain as P2; resistance onset as R1 and increased intensity of resistance that did not limit the SLR as R| (Figure 3). In their study, Hayes and Petersen[24] rated the reliability of their end-feel and pain/resistance judgements as "generally good". Intrarater kappa coefficients varied from 0.65 to 1.00 for end-feel, and intrarater weighted kappa coefficients varied from 0.59 to 0.87 for pain/resistance sequence.

The examiner passively raised the lower extremity to the point where the participant's perception of the stretch discomfort could no longer be tolerated (P2); the ROM was read off of the inclinometer. This measurement was performed prior to, immediately after, and one hour following each intervention.

Secondary outcome: Maximal perception of pain intensity at greatest stretch tolerance (end of SLR ROM) was determined via the use of a horizontal 10 centimeter visual analogue scale (VAS) with anchor points of 0 (no pain) and 10 (worst perceived pain). Participants were requested to mark the intensity of their perceived pain on the VAS using a pencil (P2). The VAS was chosen for measurement of pain because of its ease of administration and responsiveness.[25] The level of pain measurements was taken at baseline, immediately after, and one-hour post-intervention.

Intervention

The main investigator (first author) who performed the intervention on each participant and was not involved in the measurements has 30 years of experience in physical and manual therapy according to the Maitland concept.[16]

Stretching protocols

Group 1: static stretching.

Participants were asked to state which leg they usually used when kicking a ball. This was then defined as their dominant leg.

Starting position: the stretch was performed on the dominant leg with participants in the supine position on a non-adjustable treatment plinth, with the knee remaining in extension and the femur in neutral rotation. A lumbar roll was used to maintain participants' lumbopelvic lordosis in a neutral position throughout the test. The contralateral thigh remained completely in contact with the plinth, stabilized by a belt. The first author passively raised the

Figure 4. *Illustrates the straight leg raise technique for hamstring extensibility. The main investigator passively raised the leg to the point of the first sensation of stretch, waited 15 seconds until the participant could tolerate more stretching and then added a further stretch to achieve a new "tolerance point".*

Figure 5. *Illustrates the Dynamic Oscillatory Stretching technique for hamstring extensibility. The therapist raises the leg to the point of "first sensation of stretch" while the patient assists the stretch by contracting his/her hip flexor muscles, while the knee extensor maintains knee extension. The stretch is held for two seconds, and the therapist then lowers the leg to approximately 30 degrees. Thereafter the process is repeated.*

leg to the point of the first sensation of a stretch, held it for 15 seconds until the participant could tolerate more stretching, and then added a further stretch to achieve a new "tolerance point". This procedure was repeated four times for a total stretch duration of 60 seconds (Figure 4).

Group 2: dynamic oscillatory stretching

Starting position: same as for SS.

The first author passively raised the leg to the point of the first sensation of a stretch. Each participant assisted the stretch by contracting his/her hip flexor muscles, while the knee extensors maintained the position of knee extension. Hip flexor and knee extensor contractions were sustained throughout the stretch. A two-second, slow passive stretch at the end of the range was applied to assist in further extending the stretch (Figure 5). The main investigator counted 101, 102 to standardize the two second stretch. The agonist contraction was maintained throughout the stretch. This procedure was repeated 10 times over three sets. The lower extremity was stretched to a new point of tolerance with each set. The total stretching time was again 60 seconds: 2 sec x 10 repetitions x 3 sets.

For both stretching groups at the completion of the stretch, the lower extremity was allowed to rest for 10 seconds with a pillow under the knee; and thereafter measurement of SLR ROM and perceived pain intensity (stretch tolerance) at the new range was obtained.

Group 3: placebo-control

Participants in the placebo-control group received a one-minute sham ultrasound to the dorsal aspect of the foot in side lying. This procedure was chosen as a placebo due to the known absence of an anatomical and physiological relationship between the dorsum of the foot and the hamstrings muscle. Unfortunately, it is not possible to blind participants in studies of this kind. Although the control group might have realized they were not in the experimental group, the recruiting information stated that the study aimed to determine the effect of different interventions on hamstring extensibility.

Statistical Analysis

Homogeneity of group characteristics (age, height, body mass) was determined by one-way analysis of variance (ANOVA) and *Tukey's post-hoc* test. Shapiro-Wilk tests established the normal distribution of all data sets. Differences between interventions (DOS, SS, and control) for SLR and reported pain at three

Table 1. *Descriptive characteristics of 3 experimental groups (presented as group mean +/- standard deviation).*

Group	DOS	SS	Control
N (f/m)	20 (15/5)	20 (16/4)	20 (14/6)
Age (years)	22 ± 1	22 ± 1	22 ± 1
Body mass (kg)	70.9 ± 11.2	65.2 ± 10.9	68.0 ± 6.9
Height (m)	1.66 ± 8	1.64 ± 5	1.67 ± 4
BMI (kg.m^{-2})	26.1 ± 5.1	24.3 ± 4.5	24.3 ± 2.0

Data are presented as mean ± SD. DOS – dynamic oscillatory stretch, SS – static stretch. N = number of participants in each group. (f/m) designates number of females and males. No significant differences were found between groups, p < 0.05.

different time points (pre-test, post-test and post-test + 1 hour) were determined by two-way repeated measures of ANOVA. Assumptions of sphericity were assessed using the Mauchly test of sphericity, with any violations adjusted by use of the Greenhouse-Geisser correction. Where significant interaction (intervention x time) effects were found, one-way repeated measures ANOVA and *Tukey's post hoc* test were used to determine the simple main effect of the protocol. All data are reported as mean ± standard deviation level of significance, set at $p < 0.05$. Statistical analysis was performed using Statistical Package for the Social Sciences (version 22, IBM.com).

RESULTS

The mean descriptive characteristics of the three experimental groups are presented in Table 1. There were no significant differences between groups. Changes in ROM during SLR are presented in Figure 6. There was a significant interaction effect (intervention x time) for ROM. SLR was not different between groups pre-intervention (Control 73 ± 12°, SS 79 ± 8°, DOS 76 ± 10°, p = 0.322). Immediately post-intervention, both SS, and DOS groups increased their ROM above the control group (Control 73 ± 12°, SS 86 ± 8°, DOS 94 ± 11°, p < 0.001). The increased ROM in DOS post-intervention was significantly greater than for SS (p < 0.001). One hour following intervention, there was no longer any difference in ROM between the control and SS groups, but ROM in the DOS group remained elevated above both other groups (Control 73 ± 12°, SS 80 ± 8°, DOS 89 ± 12°, p = 0.001).

Changes in most intense perceived pain at the end of the range of SLR (stretch tolerance) are presented in Figure 7. A significant interaction effect (intervention x time) was present for the self-reported pain measure. Pain at the end of the range of SLR was not significantly different between groups pre-intervention (Control 4.8 ± 1.1, SS 5.4 ± 0.8, DOS 5.7 ± 1.5 AU). Immediately post-intervention, the DOS and SS groups reported a similar perception of pain, however, this was significantly greater reported pain than for the control group (Control 4.3 ± 1.3, SS 5.9 ± 0.8, DOS 5.3 ± 1.3 AU, p < 0.001). This similar pain response, however, was achieved in the statistically significantly increased ROM seen in

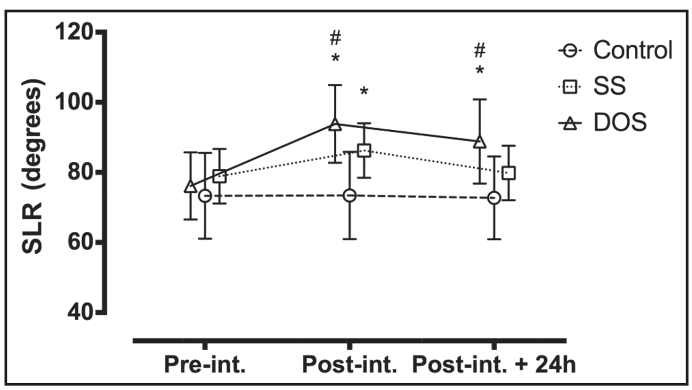

Figure 6. *Range of motion during straight leg raise test following 3 different stretch protocols.*
*SS = static stretch, DOS = dynamic oscillatory stretch. * and # indicate significant difference from control and SS conditions respectively.*

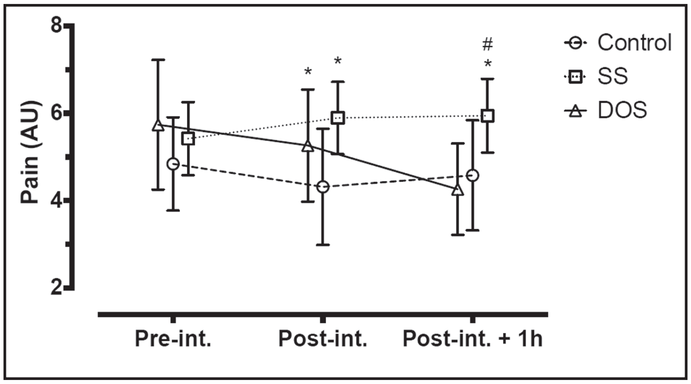

Figure 7. *Most intense perceived pain at the end range of straight leg raise test following two different stretch interventions and control.*
*SS = static stretch, DOS = dynamic oscillatory stretch. * and # indicate significant difference from control and DOS conditions respectively.*

the DOS group as compared with the SS group ($p < 0.001$). One hour following intervention, there was no longer any difference in perceived pain between the control and DOS groups, but SS pain was significantly greater than both of these groups (Control 4.6 ± 1.3, SS 5.9 ± 0.8, DOS 4.3 ± 1.0 AU, $p < 0.001$)

DISCUSSION

The results of this study demonstrate that both SS and DOS protocols can improve hamstring extensibility. However, the increased extensibility achieved within the DOS group was greater than for the SS group, both immediately and one hour following the intervention. Beyond extensibility improvements one-hour post-intervention, the DOS group pain response appeared to be less than the SS but not different from the control group, suggesting that this approach also offers improvement in stretch tolerance. The improved hamstring extensibility and perceived tolerance to the stretch demonstrated by the DOS group may support the theories of muscle property changes and reflex muscle relaxation, but is most likely explained by the improved stretch tolerance theory.[7,9,10] However, further discussion regarding the superiority of DOS is required. Hypoalgesic, biochemical, and fluid-dynamic hypoalgesic influences have been consistently documented following physiological oscillatory mobilization in both a patient population group and in asymptomatic volunteers.[26] The exact mechanism of pain relief from manual therapy techniques is unclear, but it has been suggested that pain is modulated at either the spinal cord or in higher levels within the central nervous system.[27] Wright[28] argued that passive physiological oscillatory movements preferentially activate the descending inhibitory noradrenergenic system and exert a hypoalgesic influence on the mechanical nociceptor. Given that musculoskeletal conditions appear to involve changes in mechanical nociceptors, it is possible that DOS, due to its similarity to the mechanism of passive physiological oscillatory techniques, could effectively promote pain tolerance and subsequently increase ROM. This study included only asymptomatic individuals, which raises the question of whether pain variables can be accurately measured via self-reporting in healthy individuals. The use of asymptomatic individuals is commonly reported in experimental pain studies utilizing quantitative sensory testing methodologies. These include mechanical pressure[29,30,31] and experimentally induced pain[32,33,34] with one study, like this study, measuring pain using VAS.[21] Pain variables therefore, can be used accurately when measuring healthy individuals, but any conclusions drawn from the results of this study should be applied with caution.

Having dealt with the effect of DOS on stretch tolerance, attention can be turned to the effect of neural tissue mobilization on hamstring extensibility. Decreased hamstring extensibility as evidenced by the limited range in the SLR test could also be due to altered neurodynamics of the sciatic and tibial nerves. Changes in mechanosensitivity of the sciatic nerve have been shown to reduce hamstring length in asymptomatic individuals.[8,35] Neural mobilization techniques alone[36] and in combination with static stretch[37] have been demonstrated to be effective in increasing hamstring extensibility in healthy volunteers. Nee and Butler[38] hypothesized that "oscillatory movements can have a positive impact on symptoms by improving intraneural circulation, axoplasmic flow, and neural connective tissue viscoelasticity". Altering mechanosensitivity of the posterior thigh neural system could be a plausible mechanism for increasing hamstring extensibility utilizing DOS. It is therefore suggested that neural tissue mobilization could play a significant role in improving stretch tolerance.

Immediately post-intervention, the DOS, and SS groups reported similar pain scores as a measure of stretch tolerance, but the DOS group had increased ROM. This might indicate that DOS could be more comfortably tolerated than SS. This is important because static stretching in a clinical setting can be painful. However, clinicians believe that its long-term benefits outweigh the short-term disadvantage of patient discomfort. Stretching techniques like DOS that have the capacity to modify stretch tolerance could be effective as a therapeutic stretch. This, however, requires further randomized studies on symptomatic individuals across a broader age group with longer follow-up, using stretching interventions that are effective at changing stretch tolerance. Therefore, the results of this study can be generalized only to a healthy, asymptomatic, young adult population. Enhanced understanding of the effect of stretching following the application of DOS, as a result of the findings of this study, will hopefully enable clinicians to provide more effective and scientifically-based treatment when incorporating stretching activities into rehabilitation programs.[3] This is the first study to investigate stretching utilizing dynamic oscillatory movement, with PNF and static stretching incorporated. The results of only one study have indicated that stretching is effective in achieving pain relief.[39] That study however, included a combination of manual therapy and static stretch.

CONCLUSION

The results of the current study demonstrate that improvements in hamstring extensibility can be achieved with both DOS and SS techniques. Notably, DOS showed a superior increase in extensibility immediately and one-hour post-intervention while SS had lost the increased SLR one-hour post-intervention. DOS demonstrated an increase in stretch tolerance at the newly obtained range one-hour post-intervention. The dynamic oscillatory stretching technique used in the current study could provide clinicians with an effective therapeutic stretching option for increasing extensibility with good tolerance of the technique.

REFERENCES

1. Van Wingerden JP, Vleeming A, Snijders CJ, et al. A functional-anatomical approach to the spine-pelvis mechanism: interaction between the biceps femoris muscle and the sacrotuberous ligament. *Eur Spine J* 1993;2:140-144.
2. Radwan A, Bigney KA, Buonomo HN, et al. Evaluation of intra-subject difference in hamstring flexibility in patients with low back pain: An exploratory study. *J Back Musculoskelet Rehabil.* 2015;28:61-66.
3. Heiderscheit BC, Sherry MA, Silder A, et al. Hamstring strain injuries: recommendations for diagnosis, rehabilitation, and injury prevention. *J Orthop Sports Phys Ther.* 2010;40:67-81.
4. Lankhorst NE, Bierma-Zeinstra SM, van Middelkoop M. Factors associated with patellofemoral pain syndrome: a systematic review. *Br J Sports Med.* 2013;47:193-206.
5. Van der Worp H, Van Ark M, Roerink S, et al. Risk factors for patellar tendinopathy: a systematic review of the literature. *Br J Sports Med.* 2011:bjsports84079.
6. Herbert R. The passive mechanical properties of muscle and their adaptations to altered patterns of use. *Aust J Physiother.* 1988;34:141-149.
7. Fryer G. MET: efficacy and research in: Chaitow L. Muscle Energy Techniques. 2nd ed. Churchill Livingstone. Elsevier 2013; 95-132.
8. McHugh MP, Johnson CD, Morrison RH. The role of neural tension in hamstring flexibility. *Scand J Med Sci Sports.* 2012;22:164-169.
9. Ben M, Harvey LA. Regular stretch does not increase muscle flexibility: a randomized controlled trial. *Scand J Med Sci Sports.* 2010;20:136-144.
10. Weppler CH, Magnusson SP. Increasing muscle flexibility: a matter of increasing the length or modifying sensation? *Phys Ther.* 2010;90:438-449.
11. McHugh MP, Cosgrave CH. To stretch or not to stretch: the role of stretching in injury prevention and performance. *Scand J Med Sci Sports.* 2010;20:169-181.
12. Nishikawa Y, Aizawa J, Kanemura N, et al. Immediate effect of passive and active stretching on hamstrings flexibility: a single-blinded randomized control trial. *J Phys Ther Sci .* 2015;27:3167.
13. Hindle K, Whitcomb T, Briggs W, et al. Proprioceptive neuromuscular facilitation (PNF): Its mechanisms and effects on range of motion and muscular function. *J Hum Kinet.* 2012;31:105-113.
14. Meroni R, Cerri CG, Lanzarini C, et al. Comparison of active stretching technique and static stretching technique on hamstring flexibility. *Clin J Sport Med.* 2010;20(1):8-14.
15. Mattes AL. Active isolated stretching: The Mattes Method 2012, 2nd Edition; p 157.

16. Maitland GD. Vertebral Manipulation Fifth edition. *Butterworths.* 1986:Chapter 6,106;351-364, Appendix 1.
17. Vincent K, Maigne JY, Fischhoff C, et al. Systematic review of manual therapies for nonspecific neck pain. *Joint Bone Spine.* 2013;80:508-515.
18. Bronfort G, Haas M, Evans RL, et al. Efficacy of spinal manipulation and mobilization for low back pain and neck pain: a systematic review and best evidence synthesis. *Spine J.* 2004;4:335-356.
19. Medeiros DM, Cini A, Sbruzzi G, et al. Influence of static stretching on hamstring flexibility in healthy young adults: Systematic review of meta-analysis. *Physiother Theory Pract.* 2016;32(6):438-445.
20. Fasen JM, O'Connor AM, Schwartz SL, et al. A randomized controlled trial of hamstring stretching: comparison of four techniques. *J Strength Cond Res.* 2009;23(2):660-667.
21. Davis DS, Quinn RO, Whiteman CT, et al. Concurrent validity of four clinical tests used to measure hamstring flexibility. *J Strength Cond Res.* 2008;22:583-588.
22. Neto T, Jacobsohn L, Carita AI, et al. Reliability of the Active-Knee-Extension and Straight-Leg-Raise Tests in Subjects with Flexibility Deficits. *J. Sport Rehabil .* 2014.
23. Boyd BS. Measurement properties of a hand-held inclinometer during straight leg raise neurodynamic testing. *Physio.* 2012;98:174-179.
24. Hayes KW, Petersen CM. Reliability of assessing end-feel and pain and resistance sequence in subjects with painful shoulders and knees. *J Orthop Sports Phys Ther.* 2001;31(8):432-45.
25. Chapman JR, Norvell DC, Hermsmeyer JT, et al. Evaluating common outcomes for measuring treatment success for chronic low back pain. *Spine J.* 2011;36:S54-S68.
26. Chaitow L. Manual therapies and hypoalgesia: What are the mechanisms? *J Body w Mov Ther.* 2015;19:389-390.
27. Bialosky JE, Bishop MD, Price DD, et al. The mechanisms of manual therapy in the treatment of musculoskeletal pain: a comprehensive model. *Man Ther.* 2009;14:531-538.
28. Wright A. Hypoalgesia post-manipulative therapy: a review of a potential neurophysiological mechanism. *Man Ther.* 1995;1:11-16.
29. Fernández-de-las-Peñas C, Pérez-de-Heredia M, Brea-Rivero M, et al. Immediate effects on pressure pain threshold following a single cervical spine manipulation in healthy subjects. *J Orthop Sports Phys Ther.*, 2007;37(6):325-9.
30. Fryer G, Carub J, McIver S. The effect of manipulation and mobilization on pressure pain thresholds in the thoracic spine. *Int J Osteopath Med.* 2004;7(1):8-14.
31. Vincenzino B, Cartwright T, Collins D, et al. An investigation of stress and pain perception during manual therapy in asymptomatic subjects. *Eur J Pain.* 1999;3(1):13-18.
32. Bennell K, Hodges P, Mellor R, et al. The nature of anterior knee pain following injection of hypertonic saline into the infrapatellar fat pad. *J Orthop Res*, 2004;22(1):116-121.
33. Wingenfeld K, Wolf S, Kunz M, et al. No effects of hydrocortisone and dexamethasone on pain sensitivity in healthy individuals. *Eur J Pain,* 2015;19(6):834-841.
34. Petrini L, Hennings K, Li X, et al. A human experimental model of episodic pain. *Int J Psychophysiol*, 2014;94(3):496-503.
35. Lew PC, Briggs CA. Relationship between the cervical component of the slump test and change in hamstring muscle tension. *Man Ther.* 1997;2:98-105.
36. Castellote-Caballero Y, Valenza MC, Puentedura EJ, et al. Immediate Effects of Neurodynamic Sliding versus Muscle Stretching on Hamstring Flexibility in Subjects with Short Hamstring Syndrome. *J Sports Med (Hindawi Publ Corp).* 2014;2014:127471.
37. Sharma S, Balthillaya G, Rao R, et al. Short-term effectiveness of neural sliders and neural tensioners as an adjunct to static stretching of hamstrings on knee extension angle in healthy individuals: A randomized controlled trial. *Phys Ther Sport.* 2016;17:30-37.
38. Nee RJ, Butler D. Management of peripheral neuropathic pain: integrating neurobiology, neurodynamics, and clinical evidence. *Phys Ther Sport.* 2006;7: 36-49.
39. Cunha ACV, Burke TN, França FJR, et al. Effect of global posture reeducation and static stretching on pain, range of motion, and quality of life in women with chronic neck pain: a randomized clinical trial. *Clinics - Hospital das Clinicas da Faculdade de Medicina da Universidade de Sao Paulo.* 2008;63:763-770.