Evaluating Novel Manual Therapies for the Treatment of Lower Extremity Dysfunction and Pathology: A Dissertation of Clinical Practice Improvement

A Dissertation

Presented in Partial Fulfillment of the Requirements for the

Degree of Doctor of Athletic Training

with a

Major in Athletic Training

in the

College of Graduate Studies

University of Idaho

by

Bethany Hansberger

Major Professor: Russell T. Baker, D.A.T.

Committee Members: James M. May, D.A.T.; Alan M. Nasypany, Ed.D.;

Scott W. Cheatham, D.P.T.

Department Administrator: Phillip W. Scruggs, Ph.D.

August 2016

AUTHORIZATION TO SUBMIT DISSERTATION

This dissertation of Bethany Hansberger, submitted for the degree of Doctor of Athletic Training with a Major in Athletic Training and titled "Evaluating Novel Manual Therapies for the Treatment of Lower Extremity Dysfunction and Pathology: A Dissertation of Clinical Practice Improvement," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ________________________________ Date: ____________
Russell T. Baker, D.A.T.

Committee Members: ________________________________ Date: ____________
James M. May, D.A.T.

________________________________ Date: ____________
Alan M. Nasypany, Ed.D.

________________________________ Date: ____________
Scott W. Cheatham, D.P.T.

Department Administrator: ________________________________ Date: ____________
Phillip W. Scruggs, Ph.D.

ABSTRACT

The Dissertation of Clinical Practice Improvement (DoCPI) is the pinnacle product of the University of Idaho's Doctor of Athletic Training program and serves as a representation of growth as an advanced scholarly clinician. Through the introduction of concepts such as action research (AR), evidence-based practice (EBP), and practice-based evidence (PBE), the foundations for advanced practice are established. Evidence of advanced practice is achieved through the collection of patient outcomes and dissemination of results. With a focus on lower extremity dysfunction and pathology, two manuscript reviews of novel treatment techniques are included in this comprehensive document. In addition to collecting and analyzing patient outcomes, advanced clinical practice is also achieved through participation in multi-site research. Following an exhaustive review of the literature summarized in two Critically Appraised Topic (CAT) manuscripts, an *a priori* research study was performed to identify the effects of a novel treatment technique on alleviating apparent hamstring tightness.

ACKNOWLEDGMENTS

I would like to acknowledge my appreciation to the following individuals for their encouragement and counsel whilst I pursued advanced clinical practice through the Doctor of Athletic Training (DAT) program:

Dr. Russell Baker, thank you for your realistic outlook, honest reviews, and insightful perspective. Your guidance throughout my time in the DAT program has been invaluable. Thank you for challenging me to improve in all aspects of my academic and scholarly works.

Dr. James May, thank you for being a pillar of positivity in the DAT program. Your commitment to maintaining an optimistic attitude permeates throughout every aspect of the DAT program.

Dr. Alan Nasypany, thank you for being open-minded and willing to share your knowledge. Your examples helped me to be more willing to take the initial steps towards the non-traditional treatment paradigms that now dominate my clinical practice (especially autonomic nervous system modulation).

Dr. Scott Cheatham, thank you for your eagerness to learn and your enthusiasm for the research process. I appreciate your willingness to assist in any way, from extra meetings to discussing statistics to reviewing manuscripts.

DEDICATION

To Grampa; thank you for always believing in me and supporting my endeavors to get the doctorate. Thank you for showing me what it means to “get up and go.” I am so grateful that you were able to witness this process and see this dream through to fruition.

“Commit to the Lord whatever you do, and He will establish your plans.” – Proverbs 16:3

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

NARRATIVE SUMMARY

While the original "dissertation" was conducted through oral disputation, the Age of Enlightenment during the 18^{th} century brought a format shift from spoken to written word, with a focus on scientific research rather than religion and philosophy (Willis, Inman, & Valenti, 2010). In addition to changes in the design of the dissertation, the purpose of the doctorate itself has undergone multiple revisions. The first doctorates were designed to be professional practice degrees; however, the doctoral degrees of the Middle Ages prepared students for research and academe rather than professional practice (Willis et al., 2010). Recently, some domestic and international programs have begun to return to the professional doctorate rather than the academic doctorate (McWilliam et al., 2002). The professional practice doctorate provides students with increased breadth of content while also developing depth through externally valid research that focuses on solving problems relevant to the profession. Healthcare professions such as nursing and physical therapy have implemented the terminal degree through the creation of doctorate programs (Willis et al., 2010), with athletic training now following suit with the post-professional Doctorate of Athletic Training (DAT) program.

The DAT program at the University of Idaho (UI) was the first terminal degree to be created in the athletic training profession with a clinical focus (Nasypany, Seegmiller, & Baker, 2013). The program emphasizes professional practice and encourages students to undergo a journey towards becoming scholarly clinicians. The pinnacle product of the UI DAT is the Dissertation of Clinical Practice Improvement (DoCPI), which incorporates reflection on a plan of advanced practice (PoAP), patient care outcomes, and original research manuscripts (Nasypany et al., 2013). With a focus on evidence-based practice (EBP), practice-based evidence (PBE), and action research (AR), chapter 1 of my DoCPI contains descriptions and examples of how these topics have impacted my clinical practice, resulting in the production of several manuscripts which are included as portions of subsequent chapters. Each of these manuscripts incorporates aspects of EBP, PBE, and AR.

Evidence-based practice is a process requiring the combination of evidence and theories found in research, practical expertise, and the individualized needs of each patient to make decisions about patient care (Hurley, Denegar, & Hertel, 2011). With EBP, clinical decisions in patient care are approached with an understanding of what is written in the literature as well as an awareness of clinical experiences related to specific treatments or evaluation techniques. Practice-based evidence, however, is created by clinicians as they combine, compare, and contrast results found in the literature with trends identified in their clinical practice through the collection of patient outcomes (Nasypany et al., 2013). The DAT challenges students to comprehend and utilize both EBP and PBE in their clinical practice. During my master's education, I was trained to take an EPB approach, especially when considering the efficacy of modality treatments. Taking courses in the DAT program has not only expanded upon my understanding of EBP, but has also taught me how to implement PBE in my clinical setting by incorporating an AR philosophy into my clinical practice.

Action research is a dynamic, "living" process based on continuous reflection and discussions designed to influence future research (Koshy, Koshy, & Waterman, 2011). Although AR was initially portrayed as a social psychology concept that considers how social action influences other actions (Lewin, 1947), the AR concept has expanded to include professional practice research that is answered through field work, reflection, and analysis

(Dickens & Watkins, 2006; Willis et al., 2010). Within AR there exist moments, known as critical incidents, that encourage reflective analysis (Newman, 2000). Critical incidents are those events that may seem like ordinary, daily activities that result in a finding that is unexpected or that challenges our assumptions (Newman, 1987). Clinicians partaking in AR must undergo a process of "systematic reflexivity" in which they sustain a level of awareness through continual review of and reflection upon the theories, methods, and results related to the topic of study (Coghlan & Brannick, 2005). Engaging in AR develops many of the traits associated with scholarship and becoming a scholarly clinician.

Scholars are individuals who have the ability to be flexible and open to new ideas while remaining focused and honest in their quest to hone and cultivate knowledge (Knight & Ingersoll, 1998). Advanced clinical practitioners are those who are able to gain depth of knowledge in a particular aspect of their clinical practice, particularly through reflection and critical analysis (Nasypany et al., 2013). Maintaining a fixed mindset, an unwillingness to be flexible, begets a clinical practice philosophy that is doomed to fail both the clinician and the patient.

Individuals with a fixed mindset are more focused on the appearance of intelligence and its associated praise rather than on actual learning, whereas individuals with a growth mindset are focused on overcoming challenges and finding solutions for barriers to learning (Dweck, 2008). An unexpected benefit of my DAT experience has been my change towards a growth mindset. Through the DAT program, I have been exposed to patient-centered care philosophies and novel treatment paradigms outside of my comfort zone and encouraged to incorporate those ideas into my clinical practice. The concept of collecting patient outcomes and the AR philosophy encouraged within the DAT have led me to a decision point as I go through the process of becoming a scholarly clinician, leaving me to choose whether to continue along a traditional path set in place by previous athletic trainers or to take a path towards advanced clinical practice. As evidenced in the ensuing chapters of this DoCPI, I have elected to step off the traditional route and embark upon the trail towards advanced practice. Through my experiences in the DAT program, I have come to recognize that these decision points are the ones from which I have gained the most; I identify and learn from the critical incidents along my path and then strive to incorporate them into my clinical practice. Morphing from a more rigid mindset into one of growth has been instrumental in changing how I view both myself and my profession; reflection and critical analysis from a growth mindset have allowed me to become more competent and have shaped my development as a scholarly clinician.

Seizing the role of scholarly practitioner, I have disseminated my research findings from my clinical residency through presentations and publications, activities I was uncomfortable with and tended to shy away from prior to my enrollment in the DAT program. In an original case study presented in chapter 2, I illustrate the efficacy of treating a patient diagnosed with medial tibial stress syndrome (MTSS) using neurodynamics. The results of this case were presented at a national conference, as well as published in a peer-reviewed journal. Among scholarly works, this was the first look at the treatment of MTSS with neurodynamics as a component of the patient’s care (Hansberger, Nasypany, Baker, & May, 2016). The results of the case led me to become interested in neurodynamics, establishing the assessment and treatment paradigm as one of my areas of focus for my professional future as a scholarly practitioner. Neurodynamics has been revolutionary in changing how I view and approach musculoskeletal dysfunctions, especially within the lower extremity.

A second area in which I decided to gain a depth of knowledge is autonomic nervous system modulation, especially through the use of the Primal Reflex Release Technique© (PRRT©). In a case series described in chapter 3, I utilized PRRT© to treat patients suffering from plantar fasciitis (Hansberger, Baker, May, & Nasypany, 2015). Using an *a priori* design case series approach, my patients received a standardized evaluation and treatment program after presenting with complaints of plantar fascia pain. The experience associated with my PRRT© case series sparked a desire to continue to collect patient outcomes in a meaningful manner that could later be shared with my colleagues in the profession. As an organized, focused individual, creating a well-laid out plan for collecting data through AR and then seeing it through to fruition was a pleasurable experience that also stoked my confidence and competence in my clinical care and collection of patient outcomes.

Another component of the DAT program is multi-site research, a process that entails using consistent methods and procedures across multiple settings while answering a specific research question (Herriott & Firestone, 1983). Multi-site research requires communication and an ability to work together with other individuals to achieve a common goal. An AR approach may be taken when conducting multi-site research as Lewin's idea of AR called for collaboration among researchers, encouraging interdependence, commitment, and ownership of a project through the processes of reflection and analysis (Dickens & Watkins, 2006; Lewin, 1947). As a student in the DAT program, I have been a member of two multi-site research studies, in addition to individual research endeavors using my patient outcomes information.

The first applied research topic stemmed from reflection and critical analysis of case studies completed individually by myself and peers and centered on the use of neurodynamics to treat patients with MTSS. A small group of students who commonly treat MTSS developed an *a priori* design multi-site research study considering the treatment of MTSS with neurodynamics. Although the results of the multi-site MTSS study did not confirm our hypothesis, I learned valuable information about the importance of *a priori* designs and the benefits and pitfalls of conducting multi-site research.

A second multi-site research project I was a member of considered the use of the Total Motion Release© (TMR©) forward flexion trunk twist (FFTT) to treat individuals with apparent hamstring tightness (AHT). Within the requirements of the study, my colleagues and I conducted a thorough review of the literature relevant to our topic, resulting in the creation of two critically appraised topics (CATs) that have been submitted for publication and are included in chapter 4. Represented in chapter 5, the AHT study was my longest-running multi-site research experience in the DAT program, going through multiple rounds of pilot testing before the study was officially conducted.

Working in collaboration with both peers and faculty members on projects and manuscripts has given me the ability to operate with a multitude of personality types and leadership styles, while also providing me with an opportunity to develop my own strengths and those of others. According to the Gallup® StrengthsQuest™ assessment, one of my primary strengths is that of "developer." In both my clinical residency and my schooling, I have had the opportunity to work with others while in a leadership position. I have always had a passion for teaching and coaching others and trying to identify the potential in those around me; however, it was not until my DAT experiences combined with my

StrengthsQuest™ results that I recognized what a strength it is to be able to identify areas of improvement for growth and then assist people (e.g., peers, patients, myself) in succeeding. A phrase frequently heard in the DAT classroom is “if you are not aware of it, then you will never know it.” The underlying meaning behind this phrase captures the very essence of the DAT and advanced clinical practice in that it highlights the idea that there is always room to grow, develop, and improve upon what has been established as the current standards in the profession. Only through a thirst for knowledge and subsequent quest for development, followed by critical analysis of and reflection upon the results, can true improvement in clinical practice occur.

The DoCPI is the culminating product of my journey through the DAT program, representing examples of my work which serve as testaments to my progress as a scholarly clinician. Chapter 1 highlights the theories, concepts, and philosophies that have guided my journey to advanced practice and laid the foundation for the creation of the manuscripts in the subsequent chapters. Through a willingness to step outside my comfort zone and embrace a growth mindset, I discovered neurodynamics, a paradigm used with great success in the treatment of the MTSS patient described in chapter 2. An example of my use of patient outcomes as well as PBE is contained within the third chapter. In chapter 4, I provide two CAT manuscripts that depict the conduction of a literature review from a multi-site perspective while chapter 5 focuses on original research produced via an AR, multi-site design. After being challenged over the last two years to critically examine my clinical practice and reflect upon my patient outcomes while integrating EBP, PBE, and AR, I have identified not only personal strengths and weaknesses, but also specific areas I plan to focus on (such as neurodynamics) as I continue to develop into an advanced scholarly clinician.

My DoCPI stands not only as a symbol of achievement in reaching a lifelong goal, but also as a testament to the revolutionary process I have undergone as a clinician in the UI DAT program. From utilizing EBP, PBE, and patient outcomes in my clinical practice to conducting and disseminating AR, my DoCPI is a representation of the growth I have undergone in the last two years and a symbol of where my practice may go.

References

Coghlan, D. & Brannick, T. (2005). *Doing Action Research in Your Own Organization*. London: SAGE Publications, Ltd.

Dickens, L. & Watkins, K. (2006). Action research: Rethinking Lewin. In J.V. Gallos (Ed.) *Organization Development* (185-201). San Francisco: Jossey-Bass.

Dweck, C.S. (2008). Mindsets: How praise is harming youth and what can be done about it. *School Library Media Activities Monthly, 24*(5), 55-58.

Hansberger, B.L., Baker, R.T., May, J., & Nasypany, A. (2015). A novel approach to treating plantar fasciitis – effects of primal reflex release technique: A case series. *International Journal of Sports Physical Therapy, 10*(5), 690-699.

Hansberger, B.L., Nasypany, A., Baker, R.T., & May, J. (2016). Incorporating neurodynamics in the treatment of lower leg pain: A case review. *Athletic Training and Sports Health Care*. [Accepted for publication].

Herriott, R.E. & Firestone, W.A. (1983). Multisite qualitative policy research: Optimizing description and generalizability. *Educational Leadership, 12*(2), 14-19.

Hurley, W.L., Denegar, C.R., & Hertel, J. (2011). *Research Methods: A Framework for Evidence-Based Clinical Practice*. Baltimore, MD: Lippincott Williams & Wilkins.

Knight, K.L. & Ingersoll, C.D. (1998). Developing scholarship in athletic training. *Journal of Athletic Training, 33*(3), 271-274.

Koshy, E., Koshy, V., & Waterman, H. (2011). *Action Research in Healthcare*. California: SAGE Publications, Inc.

Lewin, K. (1947). Frontiers in group dynamics: II. Channels of group life; social planning and action research. *Human Relations, 1*(2), 143-153.

McWilliam, E.L., Taylor, P., Thomson, P., Green, B., Maxwell, T., Wildy, H., & Simons, D. (2002). *Research Training in Doctoral Programs - What Can Be learned from Professional Doctorates?* Canberra, Australian Capital Territory: Department of Education, Science and Training.

Nasypany, A. M., Seegmiller, J. G., & Baker, R. T. (2013). A model for developing scholarly advanced practice athletic trainers in post-professional education programs. Athletic Trainers' Educator Conference. Dallas, TX.

Newman, J.M. (1987). Learning to teach by uncovering our assumptions. *Language Arts, 64*(7), 727-737.

Newman, J.M. (2000). Action research: A brief overview. *Forum: Qualitative Social Research, 1*(1), Art. 17.

Willis, J., Inman, D., & Valenti, R. (2010). *Completing a Professional Practice Dissertation: A Guide for Doctoral Students and Faculty*. USA: Information Age Publishing, Inc.

CHAPTER 2

ADVANCED PRACTICE MANUSCRIPT

As a clinician enrolled in the Doctorate of Athletic Training (DAT) program through the University of Idaho, I have had the opportunity to be exposed to a variety of assessment and treatment paradigms that are uncommon in traditional entry-level programs. One such paradigm is neurodynamics, a technique I have chosen to incorporate and evaluate within my clinical setting. Over the course of the last two years, neurodynamics has become one of my clinical practice focus areas, due in part to the successful results of my first attempt with incorporating neurodynamics in a case of lower leg pain. Since identifying neurodynamics as an area of success and interest in my clinical practice, I have treated several patients with the paradigm and have had opportunities to share both specific cases and information about the paradigm itself with colleagues through peer-reviewed manuscripts and presentations at professional conferences. The following is a summary of a manuscript published in *Athletic Training and Sports Health Care* (Hansberger, Nasypany, Baker, & May, 2016). Due to copyright restrictions, the complete text of the manuscript is prohibited from being included in full, so a summary has been included in this chapter.

Medial tibial stress syndrome (MTSS) is pain located along the anterior aspect of the shin that is frequently the result of an increased activity level (Galbraith & Lavallee, 2009). The condition is prevalent among individuals who run (Nielsen, Rønnow, Rasmussen, & Lind, 2014), affecting up to 44% of runners (Yagi, Muneta, & Sekiya, 2013). Typically, MTSS is treated conservatively through a combination of activity modification/rest, cryotherapy, rehabilitation exercises, compression socks, and orthotics (Galbraith & Lavallee, 2009; Winters et al., 2013). The efficacy of traditional treatments for MTSS is inconclusive in the literature (Loudon & Dolphino, 2010; Moen et al., 2012).

Neurodynamics is a treatment paradigm designed to influence the central nervous system by promoting and restoring efficient communication between the neural and non-neural structures involved with the mechanical interface (Butler, 2000; Nee & Butler, 2006; Shacklock, 2005). Normal, fluid motion is produced when the musculoskeletal and nervous systems work together, resulting in a natural sensitization of the nerve. The purpose of this case study was to describe a patient with recurrent episodes of lower leg pain who was treated successfully following the inclusion of neurodynamics into her treatment plan.

The patient, a 20-year old, Division I pole vaulter, had a history of recurrent bouts of MTSS. She rated her current pain using the Numeric Pain Rating Scale (NPRS) as a 5/10 bilaterally. The patient reported bouts of prior bilateral shin pain during the outdoor track season yearly for the previous three years. Her prior treatments included stretching and strengthening exercises, with minimal effect; her episodes resolved only with rest over the summer breaks. An initial evaluation of the current complaint revealed tenderness to palpation along the anterior and posterior tibialis, peroneus brevis, soleus, and medial periosteum; there was no tenderness over the bony structures of the lower leg, ankle, or foot.

The patient's range of motion and strength were equal bilaterally and she had no positive special tests or neurological symptoms.

The patient's initial treatment consisted of rehabilitation exercises and ice massage, as described in the literature (Galbraith & Lavallee, 2009; Winters et al., 201). No activity modifications were made and she refrained from taking non-steroidal anti-inflammatory drugs (NSAIDs). The patient reported an improvement on her NPRS to 3/10 for the left leg, without a change for the right leg, after one week of treatment. She also scored a 6.33 on the Patient Specific Functional Scale (PSFS) and a 21 on the Disablement in the Physically Active (DPA) Scale at the one week mark (PSFS and DPA Scale were not assessed at baseline). At the beginning of the second week of treatment, neurodynamic peroneal sliders were added to the patient's rehabilitation program, without any other changes to her treatment or activity level. Two days later, the patient's pain on the NPRS decreased to 0/10 bilaterally. After five days of treatment including the peroneal sliders, the patient reported continued 0/10 pain on the NPRS, as well as a 10 on the PSFS and a 0 on the DPA Scale. At three-month follow-up, the patient had continued resolution of her symptoms without recurrence.

Neurodynamics has been used with success in the upper extremity, as well as when targeting the sciatic nerve in the lower extremity (Ellis & Hing, 2008). The use of peroneal sliders, especially in the treatment of MTSS, has not been considered previously in the available literature. The case study presented in this manuscript is the first of its kind to offer clinicians a novel treatment paradigm to consider when presented with treating MTSS. Future researchers should consider increased sample size, comparison treatment groups, and the efficacy of neurodynamic sliders when nerves of the lower leg, such as tibial and sural, are included.

References

Butler, D.S. (2000). *The Sensitive Nervous System.* Adelaide, Australia: Noigroup Publications.

Ellis, R.F. & Hing, W.A. (2008). Neural mobilization: a systematic review of randomized controlled trials with an analysis of therapeutic efficacy. *J Man Manip Ther*, *16*:8-22.

Galbraith, R.M. & Lavallee, M.E.(2009). Medial tibial stress syndrome: conservative treatment options. *Curr Rev Musculoskelet Med*, *2*(3):127-133.

Hansberger, B.L., Nasypany, A., Baker, R.T., & May, J. (2016). Incorporating neurodynamics in the treatment of lower leg pain: A case review. *Athletic Training and Sports Health Care*, *8*(1), 36-39.

Loudon, J.K. & Dolphino, M.R. (2010). Use of foot orthoses and calf stretching for individuals with medial tibial stress syndrome. *Foot Ankle Spec*, *3*:15-20.

Moen, M.H., Holtslag, L., Bakker, E., Barten, C., Weir, A., Tol, J.L., & Backx, F. (2012). The treatment of medial tibial stress syndrome in athletes: a randomized clinical trial. *Sports Med Arthrosc Rehab Ther Technol*, *4*:12.

Nee, R.J. & Butler, D. (2006). Management of peripheral neuropathic pain: Integrating neurobiology, neurodynamics, and clinical evidence. *Phys Ther Sport*, *7*:36-49.

Nielsen, R.O., Rønnow, L., Rasmussen, S., & Lind, M. (2014). A prospective study on time to recovery in 254 injured novice runners. *PloS One*, *9*(6).

Shacklock, M. (2005). *Clinical Neurodynamics: A New System of Musculoskeletal Treatment.* Philadelphia: Elsevier Health Sciences.

Winters, M., Eskes, M., Weir, A., Moen, M.H., Backx, F.J., & Bakker, E.W. (2013). Treatment of medial tibial stress syndrome: A systematic review. *Sports Med*, *43*(12):1315-1333.

Yagi, S., Muneta, T., & Sekiya, I. (2013). Incidence and risk factors for medial tibial stress syndrome and tibial stress fracture in high school runners. *Knee Surg Sports Traumatol Arthrosc*, *21*:556-563.

CHAPTER 3

CLINICAL OUTCOMES MANUSCRIPT

Within the Doctorate of Athletic Training (DAT) program, there is a strong emphasis on the collection of patient outcomes information. Whether for a retrospective single case, an *a priori* design case series, or an experimental research study, utilizing patient-rated outcome measures provides valuable information to the scholarly clinician to assess patient progression with the current plan of care. Measures such as the Disablement in the Physically Active (DPA) Scale, Patient Specific Functional Scale (PSFS), and the Global Rating of Change (GRoC) function as channels for patients to subjectively mark their progress using valid scoring systems that allow for comparisons across groups or treatments. As a student in the DAT program, incorporating and obtaining patient outcomes measures has become second nature. By designing *a priori* studies that include the use of these scales, my clinical outcomes have improved following reflection and critical analysis of the results of the studies. The following is a summary of an *a priori* design research study published in the *International Journal of Sports Physical Therapy* (Hansberger, Baker, May, & Nasypany, 2015). Due to copyright restrictions, the complete text of the manuscript is prohibited from being included in full, so a summary has been included in this chapter.

Plantar fasciitis is a condition that affects approximately 4.5%-10% of runners each year (Chandler & Kibler, 1993; Lopes, Junior, Yeung, & Costa, 2012). Often insidious in nature, plantar fasciitis pain is typically located at the inferior heel and described as sharp or stabbing, with increased intensity following periods of inactivity, such as with the first steps in the morning (Cole, Seto, & Gazewood, 2005; League, 2008; Roxas, 2005). Acute plantar fasciitis can transition to a chronic diagnosis when the condition has been present for ten months or more (DiGiovanni et al., 2003; DiGiovanni, Moore, Zlotnicki, & Pinney, 2012). Differential diagnoses (e.g., tarsal tunnel syndrome) may be made based on neurological assessments (Cole et al., 2005; Lopes et al., 2012). The nervous system may play a role in plantar pain if it becomes overstimulated (Cameron, 2013; Fantazzi, Snyder, & Snyder, 2008). Primal reflexes are unlearned responses modulated through the nervous system (Kasprowics, ND). Typically used by the body as a defense mechanism, stimulation of the primal reflexes may result in pain and dysfunction if an up-regulated state is maintained for an extended period (Iams, 2012).

Primal Reflex Release Technique™ (PRRT) is a treatment paradigm focused on reducing pain by down-regulating the autonomic nervous system when it becomes too aroused (Fantazzi et al., 2008). The PRRT system provides down-regulation through light, repetitive stimulation of deep tendon reflexes designed to inhibit the pain response (Iams, 2005; Iams, 2012). A specific, five-step procedure for treating plantar fasciitis has been developed by the creators of PRRT, with treatment locations related to the sacroiliac joint, peroneal tendons, triceps surae complex, hamstring musculature, and toe flexors (Iams, 2014). The purpose of this case series was to identify the effectiveness of PRRT to reduce pain and improve function (using patient-rated outcomes measures) in physically active individuals diagnosed with plantar fasciitis.

A total of seven physically active patients (22.2±6.8 years) met the inclusion criteria for the study (an eighth patient was excluded due to location of pain). All patients were treated using an identical PRRT treatment designed for plantar fasciitis following an extensive evaluation from the athletic trainer. Patient-rated outcomes measures included the Numeric Pain Rating Scale (NPRS), Disablement in the Physically Active (DPA) Scale, and the Patient Specific Functional Scale (PSFS).

Immediate statistically significant and clinically meaningful changes were produced on the NPRS after a single treatment with PRRT (N=7; mean difference=2.06±1.27, $p \leq 0.002$, 95% CI: 1.00, 3.12; Cohen's d=1.48). In addition to the initial visit, five patients continued to receive treatment beyond the first session. All five patients were discharged pain-free after 3.33±1.97 treatments over 14.83±17.7 days. Minimal clinically important differences (MCIDs) were met for the NPRS, DPA Scale, and PSFS for those patients who remained in the study after the initial evaluation.

The cases presented in this manuscript are different from those in the available literature in that these patients had lower baseline pain levels (average 3.0 on NPRS versus 6.2-6.6 on Visual Analog Scale) (Klein et al., 2012) and were young, generally healthy, physically active individuals compared to the middle-aged, often sedentary populations found in the literature (DiGiovanni et al., 2006; Klein et al., 2012; Werner, Gell, Hartigan, Wiggerman, & Keyserling, 2010). In spite of these differences, clinically meaningful results were found after both a single treatment and after multiple treatments, with 83% of patients remaining pain-free at one and two month follow-ups. The PRRT treatment protocol utilized in this study resulted in meaningful changes in a much shorter duration of time than the eight weeks to four months prescribed for more common treatments in the literature (DiGiovanni et al., 2003; Pfeffer et al., 1999; Porter, Barrill, Oneacre, & May, 2002; Probe, Baca, Adams, & Preece, 1999).

Although this case is the first to assess the efficacy of PRRT in the treatment of plantar fasciitis, more information is necessary to determine the effect of this treatment paradigm. Future researchers should consider adding a control or comparison group in addition to a treatment group to account for the possibility of spontaneous recovery. Additional research is also needed for the efficacy of PRRT to treat other musculoskeletal conditions.

References

Cameron, M.H. (2013). *Physical Agents in Rehabilitation: From Research to Practice.* St. Louis, MO: Elsevier Saunders.

Chandler, T.J. & Kibler, W.B. (1993). A biomechanical approach to the prevention, treatment, and rehabilitation of plantar fasciitis. *Sports Medicine, 15*(5):344-352.

Cole, C., Seto, C., & Gazewood, J. (2005). Plantar fasciitis: Evidence-based review of diagnosis and therapy. *American Family Physician*, *72*:2237-2242.

DiGiovanni, B.F., Nawoczenski, D.A., Lintal, M.E., Moore, E.A., Murray, J.C., Wilding, G.E., & Baumhauer, J.F. (2003). Tissue specific plantar fascia stretching exercise enhances outcomes in patients with chronic heel pain: A prospective, randomized study. *Journal of Bone and Joint Surgery*, *85A*(7):1270-1277.

DiGiovanni, B.F., Nawoczenski, D.A., Malay, D.P., Graci, P.A., Williams, T.T., Wilding, G.E., & Baumhauer, J.F. (2006). Tissue specific plantar fascia stretching exercise improves outcomes in patients with chronic plantar fasciitis: A prospective clinical trial with 2 year follow-up. *Journal of Bone and Joint Surgery, 88A*(8):1775-1781.

DiGiovanni, B.F., Moore, A.M., Zlotnicki, J.P., Pinney, S.J. (2012). Preferred management of recalcitrant plantar fasciitis among orthopaedic foot and ankle surgeons. *Foot and Ankle International, 33*(6):507-512.

Fantazzi, F., Snyder, A., & Snyder, M. (2008 May 7). CyberPT. *Primal reflex release technique: Welcome to a paradigm shift*. Retrieved from http://www.cyberpt.com/prrt.asp. Accessed November 27 2014.

Hansberger, B.L., Baker, R.T., May, J., & Nasypany, A. (2015). A novel approach to treating plantar fasciitis – effects of primal reflex release technique: A case series. *International Journal of Sports Physical Therapy, 10*(5), 690-699.

Iams, J. (2012). Primal Reflex Release Technique. *What is the primal reflex release technique for pain relief?* Retrieved from http://www.theprrt.com/what-is-theprimal-reflex-release-technique-for-pain-relief.php. Accessed November 27, 2014.

Iams, J. (2005). When reflexes rule: A new paradigm in understanding why some patients don't get well. *Advance for Physical Therapy and Rehab Medicine*, *16*(3):41.

Iams, J. (2014). Plantar fasciitis [Video]. Primal Reflex Release Technique. Retrieved from http://www.theprrt.com/etc/video/index.php?fi le=plantar-fascitis55. Accessed August 1, 2014.

Kasprowicz, D.E. (ND) Understanding the autonomic nervous system – A missing piece in the treatment of chronic pain. Retrieved from http://www.boernepti.com/media/file/340330/Understanding%20the%20ANS.pdf. Accessed January 17 2015.

Klein, S.E., Dale, A.M., Hayes, M.H., Johnson, J.E., McCormick, J.J., & Racette, B.A. (2012). Clinical presentation and self-reported patterns of pain and function in patients with plantar heel pain. *Foot & Ankle International, 33*(9):693-698.

League, A.C. (2008). Current concepts review: Plantar fasciitis. *Foot & Ankle International, 29*(3):358-366.

Lopes, A.D., Junior, L.C.H., Yeung, S.S., & Costa, L.O.P. (2012). What are the main running-related musculoskeletal injuries? *Sports Medicine*, *42*(10):891-905.

Pfeffer, G., Bacchetti, P., Deland, J., Lewis, A., Anderson, R., Davis, W., … Smith, R. (1999). Comparison of custom and prefabricated orthoses in the initial treatment of proximal plantar fasciitis. *Foot and Ankle International, 20*(4):214–221.

Porter, D., Barrill, E., Oneacre, K., & May, B.D. (2002). The effects of duration and frequency of Achilles tendon stretching on dorsiflexion and outcome in painful heel syndrome: A randomized, blinded, control study. *Foot and Ankle International, 23*(7):619-624.

Probe, R.A., Baca, M., Adams, R., & Preece, C. (1999). Night splint treatment for plantar fasciitis: A prospective randomized study. *Clinical Orthopaedics and Related Research, 368*:190-195.

Roxas, M. (2005) Plantar fasciitis: Diagnosis and therapeutic considerations. *Alternative Medicine Review*, *10*(2):83-93.

Werner, R.A., Gell, N., Hartigan, A., Wiggerman, N., Keyserling, W.M. (2010). Risk factors for plantar fasciitis among assembly plant workers. *PM&R, 2*(2):110-116.

CHAPTER 4

LITERATURE REVIEW: CRITICALLY APPRAISED TOPICS (CATs)

Changes in Hamstring Range of Motion Following Proprioceptive Neuromuscular Facilitation Stretching Compared with Static Stretching: A Critically Appraised Topic

Accepted author manuscript version reprinted, by permission, from the *International Journal of Athletic Therapy & Training*, 2016 (in press). (Appendix A)

Clinical Scenario

Stretching is commonly used in the medical, health, and fitness fields, as well as in school and military settings to increase flexibility and range of motion (ROM) at various joints (Decoster, Cleland, Altieri, & Russell, 2005; Hartig & Henderson, 1999; Pope, Hierbert, Kirwan, & Graham, 2000). Static stretching has been used for many years and requires the individual to lengthen the muscle to end range and hold this position for a set amount of time (Bandy & Sanders, 2001; Davis, Ashby, McCale, McQuain, & Wine, 2005; Puentedura et al., 2011). Numerous studies have been performed to understand appropriate stretch duration; however, treatment application ranges between five to 60 seconds (Bandy, Irion, & Briggler, 1997; Bandy & Sanders, 2001; Cipriani, Abel, & Pirrwitz, 2003; Roberts & Wilson, 1999). Proprioceptive neuromuscular facilitation (PNF) stretching is another type of stretching used frequently to increase ROM (Davis et al., 2005; Lim, Nam, & Jung, 2014). A combination of contraction and relaxation of either agonist or antagonist muscles is used during PNF stretching (Davis et al., 2005; Kisner & Colby, 2002; Lim et al., 2014; Puentedura et al., 2011). Although both static and PNF stretching techniques have been touted as effective, there remains a need to identify whether one method is more effective than the other when focusing on the hamstrings musculature. Therefore, critically appraising the efficacy of static versus PNF stretching in individuals with tight hamstrings may offer important insight into use of these techniques in clinical practice when treating individuals presenting with tight hamstrings.

Focused Clinical Question

In individuals with hamstring tightness, what is the effect of using PNF stretching compared to static stretching on traditional measures of hamstring ROM?

Search Strategy

A computerized search was completed in April 2015 (Figure 4.1).

Terms Used to Guide Search Strategy

- **P**atient/ Client group: hamstring tightness; hamstring
- **I**ntervention/Assessment: PNF OR proprioceptive neuromuscular facilitation
- **C**omparison: static stretching
- **O**utcome: flexibility OR range of motion

Sources of Evidence Searched

- CINAHL Plus
- Health Source
- SPORTDiscus
- PubMed Central
- Additional references obtained via reference list review and hand search

Inclusion Criteria

- Limited to studies that compared PNF stretching to static stretching
- Limited to studies that included individuals classified with tight hamstrings but absent of any additional pathology. Tight hamstrings are defined as 20° from vertical on the

knee extension angle (KEA) (Davis et al., 2005) or active knee extension (AKE) (Lim et al., 2014; Puentedura et al., 2011) measurement with the hip at 90° of flexion

- Limited to articles written in the English language
- Limited to articles written in the last 10 years (2005-2015)
- Limited to Level 4 evidence or higher

Exclusion Criteria

- Studies that used minors as participants
- Studies that used an injured population as participants
- Studies that did not compare PNF stretching to static stretching
- Studies that did not include pre- and post-treatment mean ROM outcomes

Evidence Quality Assessment

Validity of the selected studies was assessed using the Physiotherapy Evidence Database (PEDro) scale. The three included articles were identified on the PEDro website with accepted and approved scores; these scores were utilized in this critically appraised topic (CAT) (PEDro, 2015).

Results of Search

Three relevant studies were located using the search terms identified in the *Search Strategy* section. As described in Table 4.1, the studies selected for inclusion in this CAT were identified as the best evidence. The authors of these Level 2 studies considered the effects of static stretching in comparison to PNF stretching on traditional measures of ROM in individuals classified with hamstring tightness.

Summary of Search, Best Evidence Appraised, and Key Findings

- The literature search identified 202 studies; two randomized controlled trials (RCT) and one comparative crossover study met the inclusion and exclusion criteria (Table 4.1).
- In all of the studies that met inclusion and exclusion criteria, PNF stretching was compared to static stretching, with hamstring ROM measurements as a primary outcome measure. In one study, an additional comparison was made to active self-stretch (Davis et al., 2005).
- In the three studies that met inclusion/exclusion criteria, hamstring tightness was determined by the AKE (Lim et al., 2014; Puentedura et al., 2011) or KEA (Davis et al., 2005). Tight hamstrings are defined as 20° from vertical on the KEA (Davis et al., 2005) or AKE (Lim et al., 2014; Puentedura et al., 2011) measurement with the hip at 90° of flexion.
- In all three studies, ROM measurements were taken with the participants in supine with the contralateral limb secured to the table with Velcro straps. The involved limb was placed in a 90° of hip and knee flexion. The participants either actively extended the knee (Davis et al., 2005; Lim et al., 2014) or an examiner passively extended the knee to record the measurement (Puentedura et al., 2011). The AKE (Lim et al., 2014; Puentedura et al., 2011) or KEA (Davis et al., 2005) measurements were recorded using a digital inclinometer (Davis et al., 2005; Puentedura et al., 2011) or a manual protractor (Lim et al., 2014).
- The PEDro scores were obtained from the Physiotherapy Evidence Database. The average score for included articles was 4.33/10.

- Of the articles included, both Puentedura et al. (2011) and Lim et al. (2014) indicated that both PNF and static stretching resulted in significant gains on the AKE with no significant difference between techniques; however, Davis et al. (2005) reported that static stretching was more effective. The best evidence for stretching techniques to increase ROM in individuals with tight hamstrings remains inconclusive.

Results of the Evidence Quality Assessment

As indicated previously, the PEDro scores provided guidance in determining the validity of each article. Evaluating the articles based on the PEDro criteria indicated lower validity with scores of three (Davis et al., 2005) and five (Lim et al., 2014; Puentedura et al., 2011). Areas such as eligibility criteria (Davis et al., 2005; Lim et al., 2014), concealing allocation of subjects (Davis et al., 2005; Puentedura et al., 2011), blinding (subjects/therapists), follow-up, and an intent to treat analysis were non-existent in the majority of the articles leading to the lower PEDro scores (Table 4.2).

Clinical Bottom Line

A common consensus in the literature is that PNF and static stretching results in increased ROM on the AKE test in individuals with hamstring tightness. The effectiveness of PNF stretching compared to static stretching, however, is inconclusive. Davis et al. (2005) found that static stretching was more effective than PNF stretching, while Lim et al. (2014) and Puentedura et al. (2011) determined that both methods were equally effective at increasing ROM measures in healthy individuals with tight hamstrings.

Strength of Recommendation

There is Level 1b (Davis et al., 2005; Lim et al., 2014) and Level 2b (Puentedura et al., 2011) evidence that PNF stretching performs as well as static stretching at increasing measures of hamstring ROM in individuals with limited hamstring flexibility. The Oxford Center for Evidence-Based Medicine recommends a Level 1b for individual randomized controlled trials and Level 2b for individual cohort studies (OCBM, 2016)

Implications for Practice, Education, and Future Research

Several researchers have performed comparison studies to determine the most effective stretching technique and protocol for increasing ROM measures. A previous systematic review of PNF was performed to complete general comparisons for PNF and static stretch techniques for ROM gains. The previous systematic review was published in 2006, and included studies that were not exclusive to hamstring ROM (Sharman, Cresswell, & Riek, 2006). Therefore, there was a need to critically appraise the literature regarding the effects of PNF and static stretching on hamstring ROM.

In the appraisal of the three included studies in this CAT, Davis et al. (2005) found static stretching to be more effective at increasing KEA measurements than PNF based on reciprocal inhibition (i.e., agonist contraction) and active self-stretch. The researchers attributed the superior ROM gains of the static stretch intervention to the facilitation of the GTO during the static stretch, whereas the active contraction of the agonist muscle during the PNF stretch may facilitate the hamstring muscles, limiting the muscles' ability to relax and elongate (Davis et al., 2005; Sharman et al., 2006). In contrast, Lim et al. (2014) found both static stretch and PNF hold-relax technique to be effective at increasing AKE measurements acutely; however, no significant difference was found between the stretching techniques. These outcomes were comparable to Puentedura et al. (2011) who compared similar stretch interventions.

The lack of significant findings between interventions could be attributed to the variance in methodology for both the static and PNF stretching interventions. First, for the static stretch intervention, Lim et al. (2014) and Puentedura et al. (2011) performed a single treatment session consisting of one or two sets of 30 second stretches, respectively. Davis et al. (2005) utilized two sets of 30 seconds performed three times per week over four weeks. Davis et al. (2005) asserted that significant hamstring length cannot be achieved utilizing a protocol that includes a duration of less than two weeks and a 30 second stretch intervention. Other researchers have supported this theory by suggesting that a single, same-day series of an acute static stretch intervention will produce only transient ROM gains (DePino, Webright, & Arnold, 2000; Magnusson et al., 1996; Weppler & Magnusson, 2010; Zito, Driver, Parker, & Bohannon, 1997).

Due to the lack of consistent methodology and results within the static stretching literature, comparison between the studies is difficult and clinical relevance of the results is questionable. Davis et al. (2005) applied a passive straight leg raise (PSLR) to the point of a strong, but tolerable stretch sensation for the subject. Similarly, Lim et al. (2014) also applied a PSLR; however, the stretch was applied to the point of light tolerable pain for the subject. The methods of Puentedura et al. (2011) were significantly different and lack clinical relevance because of the inclusion of a pulley system that applied an arbitrarily chosen amount of torque to provide the passive stretch.

The lack of significant findings between interventions may also be attributed to the variance in methodology for the PNF stretching technique. Davis et al. (2005) utilized an agonist contraction method for PNF stretching that involved a single 10 second active concentric contraction of the quadriceps muscle followed by a 30 second static stretch hold.

In contrast, Lim et al. (2014) incorporated a PNF hold-relax technique where subjects isometrically contracted their hamstrings against resistance for six seconds followed by a five second relaxation period, for a total of three sets. Additionally, Puentedura et al. (2011) also utilized the PNF hold-relax technique with a 10 second isometric contraction followed by a 10 second passive stretch for four total sets.

Based on the appraisal of the available evidence and identifying inconsistent stretch intervention methodology, determining a superior stretch intervention when comparing static to PNF stretching cannot be accurately accomplished. A comparison of the studies is difficult due to methodological differences. Additional high quality studies with standardized PNF and static stretching protocols are needed to determine the most effective stretching intervention. Further, if researchers are hoping to impact clinical practice and determine the most effective stretching interventions that will translate to individual care, the application of the techniques that can be used within a clinic should be considered when determining methodology.

Based on the findings of the researchers, it appears that clinicians may utilize either static stretching or PNF stretching to achieve acute modest gains in ROM; however, more high-quality research must be performed utilizing consistent methodology to determine the clinical efficacy of each stretching intervention. Additionally, both PNF and static stretching techniques should be compared to other techniques aimed at increasing ROM to determine the most effective intervention for clinical practice. Future studies should be focused on identifying the most effective stretching protocol for increasing ROM, both short and long term, using a high quality blinded randomized control trial. The current CAT should be reviewed in two years to identify whether additional evidence exists that may alter the clinical bottom line of this clinical question.

Figure 4.1. Search strategy

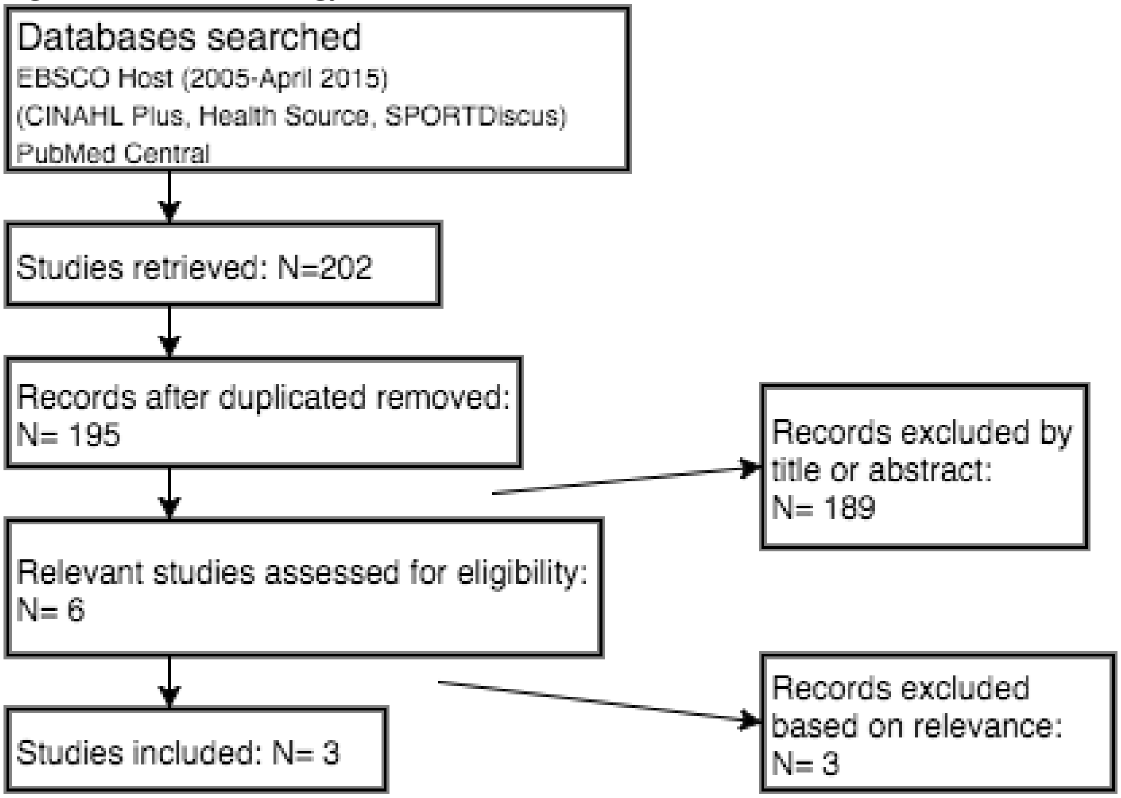


Table 4.1 Characteristics of Included Studies

Authors	**Davis et al**	**Lim et al**	**Puentedura et al**
Title	The Effectiveness of 3 Stretching Techniques on Hamstring Flexibility using Consistent Stretching Parameters	Effects on Hamstring Muscle Extensibility, Muscle Activity, and Balance of Different Stretching Techniques	Immediate effects of quantified hamstring stretching: Hold-relax proprioceptive neuromuscular facilitation versus static stretching
Study Design	Randomized controlled trial	Randomized controlled trial	Comparative study
Participants	19 subjects (11 males, 8 female) ages 23.1±1.5, range 21-35 years.	48 Adult males, age range 20-30; static stretch (n=16) 22.25±2.29 years, PNF (n=16) 23.50±2.16 years, and control (n=16) 22.38±2.31 years.	30 subjects (17 male / 13 female) mean age 25.7±3.0, range 22-17 years.
Inclusion and Exclusion Criteria	<u>Inclusion:</u> Tight hamstring as defined by a 20° Knee Extension Angle (KEA) with the hip in 90° of hip flexion; between 18 and 40 years of age. <u>Exclusion:</u> Previous history of lower-extremity pathology, which may adversely affect hamstring flexibility length.	<u>Inclusion:</u> Male adults in their 20s and 30s; Extensibility of hamstring muscle reduced by 20° as measured by the Active Knee Extension (AKE) Test. <u>Exclusion:</u> History of injury which could have affected hamstring muscle extensibility: herniated intervertebral disk, cruciate ligament damage, femoral muscle or hamstring muscle damage, sciatic neuralgia, etc. as well as dose who were or a history of surgery nervous or musculoskeletal systems, within the last 5 years, currently engaged in exercises such as stretching, yoga, Pilates, etc. for improving flexibility.	<u>Inclusion:</u> Not listed <u>Exclusion:</u> (possible) pregnancy, hamstring injury within the past year, exceeding 80° in the initial Active Knee Extension (AKE) test, and/or participation in sports that required regular hamstring stretching.
Interventions Investigated	Group 1 (active self-stretch): Supine, hip actively flexed to 90°, knee actively extended for 30 seconds, repeated bilaterally; 3x/week, 4 weeks. Group 2 (manual static stretch): Supine, Passive Knee Extension (PKE)'point of strong but tolerable stretch,' 30 second hold; repeated bi-laterally; 3x/week, 4 weeks. Group 3 (Proprioception Neuromuscular Facilitation	Static Stretch Group: Supine, Passive Straight Leg Raise (PSLR) - 1 set of 30 seconds. PNF Stretch Group: Hold-Relax Technique – Supine with PSLR, then 6 second contraction of hamstring, leg then lowered to table for 5 seconds repeated for total of 3 sets. Control Group: No intervention specified.	Static Stretch (SS) Group: 2 sets of 30 second stretches, 10 second rest interval between sets. PNF Stretch Group: Hold-Relax Technique – Supine with leg raised to end range, 4 sets of 10 second isometric contraction with 10 second passive stretch intervals.

	(PNF)-Reciprocal Inhibition): Supine, PKE to 'point of strong but tolerable stretch', 10 second knee extension contraction; reposition to new 'point of strong but tolerable stretch' and 30 second hold; repeated bi-laterally; 3 x per week, 4 weeks Group 4 (control): No intervention.		Stretching interventions were applied using a custom pulley-weight system (weight proportional to 5% of subject's body mass and discomfort rating mean of 8.29 PNF, 8.06 SS).
Outcome Measures	Range of Motion (ROM) using Knee Extension Angle	ROM using Active Knee Extension (AKE); maximum voluntary isometric contraction using surface electromyography; static balance using force measuring plate	ROM using AKE
Main Findings	At week 2, no significant increase of ROM in all four groups compared to control group. Static stretch showed significant increase over baseline. At week 4, all three treatment groups show an increase of ROM over baselines, but only static stretch had significant increase over control group from baseline (Static Stretch: Mean Difference 23.7°, Control Group: Mean Difference 3.2°). Achieved a *MCID. Significant interaction between intervention and length of program ($p < .0016$).	Significant increase of ROM in both stretching groups ($p < 0.05$) compared to control No significant difference between stretching interventions. (Static Stretch: Mean Difference 9.62°, PNF Stretch: Mean Difference 11.87°). Achieved a *MCID. No significant differences in muscle activation or balance between groups.	Significant increase of ROM compared to control condition (PNF/Control $p < .0005$; SS/Control $p = .011$). No significant difference between stretching interventions. (PNF: Mean Difference 8.9°±7.7, Static: Mean Difference 9.1°±8.9, Control: Mean Difference 1.5°±9.3). Achieved a *MCID.
Level of Evidence	1b	1b	2b
Validity Score	PEDro 3/10	PEDro 5/10	PEDro 5/10
Conclusion	Static stretching was more effective than PNF stretching in individuals presenting with hamstring tightness.	Both static and PNF stretching are effective at increasing ROM in individuals presenting with hamstring tightness.	Both static and PNF stretching are effective at increasing ROM in individuals presenting with hamstring tightness.

****The Minimal Clinically Important Difference (MCID) is a difference of 5 degrees (Chaudhary, Beaupre, & Johnston, 2008).*

Table 4.2 Results of PEDro scale

	Davis et al	**Lim et al**	**Puentedura et al**
1. Eligibility criteria specified (yes/no; not included in overall score)	No	No	Yes
2. Subjects randomly allocated to groups (yes/no)	Yes	Yes	Yes
3. Allocation was concealed (yes/no)	No	Yes	No
4. Groups similar at baseline (yes/no)	No	Yes	Yes
5. Subjects were blinded to group (yes/no)	No	No	No
6. Therapists who administered therapy were blinded (yes/no)	No	No	No
7. Assessors were blinded (yes/no)	Yes	No	Yes
8. Minimum 85% follow-up (yes/no)	No	No	No
9. Intent to treat analysis for at least 1 key variable (yes/no)	No	No	No
10. Results of statistical analysis between groups reported (yes/no)	Yes	Yes	Yes
11. Point measurements and variability reported (yes/no)	No	Yes	Yes
Overall Score (out of 10)	3/10	5/10	5/10

References

Bandy, W.D., Irion, J.M., & Briggler, M. (1997). The effect of time and frequency of static stretching on flexibility of the hamstring muscles. *Physical Therapy*, *77*(10), 1090–1096.

Bandy, W.D. & Sanders, B. (2001). *Therapeutic Exercise: Techniques for Intervention.* Baltimore, MD: Lippincott Williams & Wilkins.

Chaudhary, R., Beaupre, L.A., & Johnston, D.W. (2008). Knee range of motion during the first two years after use of posterior cruciate-stabilizing or posterior cruciate-retaining total knee prostheses. *J Bone Joint Surg*, *90*(12):2579-2586.

Cipriani, D., Abel, B., & Pirrwitz, D. (2003). A comparison of two stretching protocols on hip range of motion: implications for total daily stretch duration. *The Journal of Strength & Conditioning Research*, *17*(2), 274-278.

Davis, D.S., Ashby, P.E., McCale, K.L., Mcquain, J.A., & Wine, J.M. (2005). The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. *The Journal of Strength & Conditioning Research*, *19*(1), 27-32.

Decoster, L.C., Cleland, J., Altieri, C., & Russell, P. (2005). The effects of hamstring stretching on range of motion: A systematic literature review. *J Orthop Sports Phys Ther*, *35*(6), 377-387.

DePino, G.M., Webright, W.G., & Arnold, B.L. (2000). Duration of maintained hamstring flexibility after cessation of an acute static stretching protocol. *Journal of Athletic Training*, *35*(1), 56–59.

Hartig, D.E. & Henderson, J.M. (1999). Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *Am J Sports Med*, *27*(2):173-176.

Kisner, C. & Colby, L.A. (2002). *Therapeutic Exercise: Foundations and Techniques.* (5th ed.) Philadelphia, PA: F.A. Davis Company.

Lim, K.I., Nam, H.C., & Jung, K.S. (2014). Effects on hamstring muscle extensibility, muscle activity, and balance of different stretching techniques. *J Phys Ther Sci, 26*(2), 209-213.

Magnusson, S.P., Simonsen, E.B., Aagaard, P., Dyhre-Poulsen, P., McHugh, M.P., & Kjaer, M. (1996). Mechanical and physical responses to stretching with and without preisometric contraction in human skeletal muscle. *Archives of Physical Medicine and Rehabilitation, 77*(4), 373–378.

Oxford Center for Evidence-Based Medicine (OCBM). Centre for Evidenced-Based Medicine. http://www.cebm.net. Updated 2016. Accessed February 2, 2016.

Physiotherapy evidence database. PEDro website. http://www.pedro.org.au/. Updated June 1, 2015. Accessed June 11, 2015.

Pope, R.P., Hierbert, R.D., Kirwan, J.D., & Graham, B.J. (2000). A randomized trial of preexercise stretching for prevention of lower-limb injury. *J Am College Sports Med*, *32*(2):271-277.

Puentedura, E.J., Hujibregts, P.A., Celeste, S., Edwards, D., In, A., Landers, M.R., & Fernandez-de-las-Penas, C. (2011). Immediate effects of quantified hamstring stretching: Hold-relax proprioceptive neuromuscular facilitation versus static stretching. *Physical Therapy in Sport*, *12*(3), 122-126.

Roberts, J.M., & Wilson, K. (1999). Effect of stretching duration on active and passive range of motion in the lower extremity. *British Journal of Sports Medicine*, *33*(4), 259–263.

Sharman, M.J., Cresswell, A.G., & Riek, S. (2006). Proprioceptive neuromuscular facilitation stretching : mechanisms and clinical implications. *Sports Medicine (Auckland, N.Z.)*, *36*(11), 929–939.

Weppler, C.H., & Magnusson, S.P. (2010). Increasing muscle extensibility: A matter of increasing length or modifying sensation? *Physical Therapy*, *90*(3), 438–449.

Zito, M., Driver, D., Parker, C., & Bohannon, R. (1997). Lasting effects of one bout of two 15- second passive stretches on ankle dorsiflexion range of motion. *The Journal of Orthopaedic and Sports Physical Therapy*, *26*(4), 214–221.

Changes in Hamstring Range of Motion Following Neurodynamic Sciatic Sliders: A Critically Appraised Topic

Accepted author manuscript version reprinted, by permission, from the *The Journal of Sport Rehabilitation*, 2016 (Appendix B)

Clinical Scenario

Hamstring tightness (HT), a common condition across all age groups (Youdas, Krause, Hollman, Harmsen, & Laskowski, 2005), has classically been thought to be caused by a reduction in tissue length leading to muscular strain and dysfunctional or restricted movement. Traditionally, HT has been addressed via static, dynamic, and proprioceptive neuromuscular facilitation (PNF) stretching techniques aimed at increasing range of motion (ROM) by treating what is assumed to be a tissue length issue in the hamstring muscle group (Decoster, Cleland, Altieri, & Russell, 2005). Recently, researchers have questioned the efficacy of stretching as a treatment method for increasing ROM compared to other techniques (Fox, 2006). Neurodynamic sliding (NDS) integrates both the musculoskeletal and nervous systems through a "flossing" of the nerves to achieve pain reduction or increased ROM in the extremities (Shacklock, 1995). The use of NDS has recently been proposed as an alternative to stretching for patients with HT by addressing the neural factors of tightness without stretching the hamstring muscle tissue (Castellote-Caballero, Valenza, Puentedura, Fernandez-de-las-Penas, & Albuquerque-Sendin, 2014; Pagare, Ganacharya, Sareen, & Palekar, 2014; Vidhi et al., 2014). Several recent studies have examined the effectiveness of stretching compared to NDS (Castellote-Caballero et al., 2014; Pagare et al., 2014; Vidhi et al., 2014). Therefore, examining the evidence for NDS interventions versus traditional stretching techniques may offer more insight into practical clinical techniques for addressing patients with HT.

Focused Clinical Question

In an active population, what is the effect of using NDS compared to static or PNF stretching on traditional measures of hamstring ROM?

Summary of Search, Best Evidence Appraised, and Key Findings

- The literature search identified six studies. Of the six studies, one study was excluded as a duplicate study, two studies were excluded based on their title or abstract, and no studies were excluded based on lack of relevance to the critically appraised topic (CAT) (Figure 4.2).
- Two randomized controlled trials (RCT) and one comparative study met the inclusion and exclusion criteria (Table 4.3).
- All studies compared NDS targeting the sciatic nerve to stretching, with hamstring ROM measurements as a primary outcome measure. Both PNF (Vidhi et al., 2014) and static (Castellote-Caballero et al., 2014; Pagare et al., 2014) stretching were included as comparisons.
- In the included studies, all researchers agreed that NDS targeting the sciatic nerve resulted in significant gains in ROM; however, only one group of researchers (Castellote-Caballero et al., 2014) reported NDS to be more effective than stretching. The double-blinded RCT had a large sample size and was the highest quality study included in the CAT, according to the Physiotherapy Evidence Database (PEDro) scale.

- The authors of this CAT independently completed the PEDro scale and a consensus was obtained and determined for each article. The average score for included articles was 5/10.

Clinical Bottom Line

Evidence exists to support the use of NDS to increase measures of hamstring ROM in participants who present with limited hamstring flexibility; however, the effectiveness of NDS compared to traditional stretching is inconclusive. Castellote-Caballero et al. (2014) demonstrated NDS was more effective than static stretching at increasing hamstring ROM measurements, while Pagare et al. (2014) reported no difference between NDS and static stretching. Vidhi et al. (2014) reported PNF stretching was superior to NDS at increasing hamstring ROM.

Strength of Recommendation

Grade B evidence exists that NDS performs as well as traditional stretching techniques at increasing measures of hamstring ROM in participants with limited hamstring flexibility. The Strength of Recommendation Taxonomy (Ebell et al., 2004) recommends a grade of B for inconsistent Level 1 evidence or Level 2 evidence.

Search Strategy

A computerized search was completed in April 2015 (Figure 4.2).

Terms Used to Guide Search Strategy

- **P**atient/ Client group: hamstring tightness; hamstring
- **I**ntervention/Assessment: neurodynamic or slider or sciatic*
- **C**omparison: static stretching; PNF stretching
- **O**utcome: flexibility or range of motion

Sources of Evidence Searched

- CINAHL Plus
- Health Source
- MEDLINE
- SPORTDiscus
- Additional references obtained via reference list review and hand search

Inclusion Criteria

- Limited to studies that compare NDS targeting the sciatic nerve to stretching
    - *Excluded studies based on criteria*
        - Trampas A, Kitsios A, Sykaras E, Symeonidis S, Lazarou L. Clinical massage and modified proprioceptive neuromuscular facilitation stretching in males with latent myofascial trigger points. *Physical Therapy in Sport*. 2010;11(3):91-98.
        - Szlezak AM, Georgilopoulous P, Bullock-Saxton JE, Steele MC. The immediate effect of unilateral lumbar Z-joint mobilization on posterior chain neurodynamics: A randomized controlled study. *Manual Therapy*. 2011;16(6):609-613.
- Limited to articles written in the English language
- Limited to articles written in the last 10 years (2006-2015)
- Limited to humans

Exclusion Criteria

- Studies that used minors as participants
- Studies that used an injured population as participants

- Studies that used sciatic tensioners instead of sciatic sliders
- Studies that combined sciatic sliders with stretching as treatment
- Studies that did not include pre- and post-treatment mean ROM outcomes

Results of Search

Three relevant studies were located using the above search terms (Table 4.3). Validity of the selected studies was identified using the PEDro scale (Tables 4.4 & 4.5). Each author independently reviewed the studies and completed the checklist. All authors met to determine agreement for each item on the checklist.

Best Evidence

As described in Table 4.3, the studies selected for inclusion in this CAT were identified as the best evidence. The authors of these level 2 or higher studies considered the use of NDS targeting the sciatic nerve on traditional measures of ROM in comparison to traditional stretching.

Implications for Practice, Education and Future Research

The studies included in this CAT were conducted to identify the effect of NDS targeting the sciatic nerve compared to stretching on hamstring ROM measures in a healthy population. In regards to the indications for use of NDS for the treatment of HT, heightened neural mechanosensitivity may cause pathomechanical dysfunction, such as muscular tightness (Shacklock, 1995). The “tightness” reported by the patient may be based on a perception of tightness, rather than a tissue length issue (Weppler & Magnusson, 2010). Addressing the neural component within the muscle tissue may result in increased measures of ROM (Shacklock, 1995). Therefore, NDS have been offered as a method to increase ROM compared to traditional stretching within rehabilitation programs.

The researchers of the three studies examined in this CAT identified NDS to be effective as a stand-alone treatment; however, the efficacy of using sciatic sliders compared to stretching in the treatment of hamstring tightness is inconclusive. In the highest quality study available, Castellote-Caballero (2014) randomized 120 individuals with bilateral complaints of HT and decreased ROM on the passive straight leg raise test (PSLR). Following statistical analysis, the researchers reported that the use of NDS was more effective at increasing ROM than stretching, and that both NDS and stretching were more effective at increasing ROM than a placebo group. The findings were in contrast to those of researchers who conducted less rigorous studies and found there was either no difference (Pagare et al., 2014) or that stretching was more effective than NDS in the treatment of participants with apparent HT (Vidhi et al., 2014). The researchers who compared NDS directly to stretching, however, have not utilized consistent methodologies, which makes it difficult to assess outcomes across the limited evidence available (Castellote-Caballero et al., 2014; Pagare et al., 2014; Vidhi et al., 2014). For example, when evaluating the three studies included in this CAT, three of the primary inconsistencies are variations in the method of assessment, application of the stretching intervention, and the application of NDS.

The assessment methodology differed between the three studies. The active knee extension (AKE) was the method of assessment in one study (Vidhi et al., 2014) while the PSLR was utilized in the other studies (Castellote-Caballero et al., 2014; Pagare et al., 2014) included in this CAT. The methodological discrepancies in assessment of hip flexion angle and knee extension angle are important, because they are two methods that are commonly thought to represent HT. The tension of the hamstring musculature may be a limiting factor for both the AKE and PSLR, and may differ between passive and active motions, possibly translating to differences in effectiveness of the treatment intervention between the studies.

In addition to assessment type, the number of treatment sessions and type of intervention differed between the studies. Castellote-Caballero et al. (2014) found that a single application of NDS was more effective at increasing ROM than static stretching while Pagare et al. (2014) determined both NDS and static stretching significantly increased ROM equally following three sessions over a one week period. Another group of researchers also used three treatment sessions, but had participants perform hold-relax PNF as the comparison treatment rather than static stretching (Vidhi et al., 2014). The researchers determined that both PNF and NDS interventions were effective at increasing ROM; however, the PNF stretching demonstrated greater efficacy.

The last inconsistency in the studies is observed in the difference between the applications of the NDS treatment. In the application of NDS, Vidhi et al. (2014) and Pagare et al. (2014) used a seated position while Castellote-Caballero et al. (2014) used a supine position. Similarly conflicting, overpressure was only used by Vidhi et al. (2014), possibly contributing towards the differences identified between NDS and PNF treatments. Lastly, each of the three researchers also chose to mobilize different joints within their sciatic slider treatments. Mobilizing different joints may affect the amount of nerve excursion, possibly affecting the treatment outcome (Coppieters & Butler, 2008).

Clinicians should use caution when interpreting these results in an injured population as all three of the studies used subjects categorized with HT but who were otherwise apparently healthy. Based on the studies examined in this CAT, additional high quality studies are needed to determine the effects of NDS on ROM measures in various populations.

Injured populations (such as those with altered nervous system function) should be examined to determine their response to NDS treatments. Future researchers should identify the most effective NDS protocol for increasing ROM. Further, the researchers should identify the immediate, short and long-term effects of the intervention. The current CAT should be reviewed in two years to identify whether additional evidence exists that may alter the clinical bottom line of this clinical question.

Figure 4.2. Search strategy

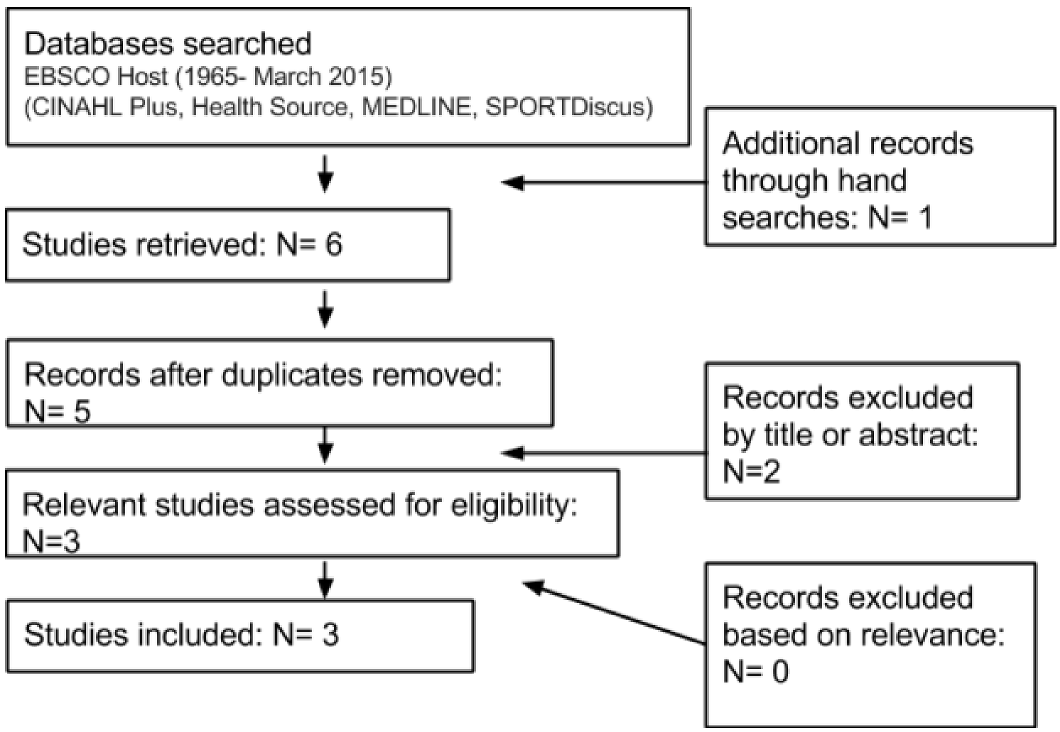


Table 4.3 Summary of Study Designs of Articles Retrieved

Level of evidence	**Study design**	**Number located**	**Reference**
1b	Randomized, double-blinded controlled trial	1	Castellote-Caballero et al
2b	Randomized, controlled trial	1	Pagare et al
	Comparative Study	1	Vidhi et al

Table 4.4 Characteristics of Included Studies

	Castellote-Caballero et al	**Pagare et al**	**Vidhi et al**
Study Design	Randomized, double-blinded controlled trial	Randomized, controlled trial	Comparative study
Participants	120 patients (60 female, 60 male; mean age 33.4 ± 7.4, range 20–45 years) with decreased PSLR ROM, otherwise apparently healthy.	30 male football players (NDS group 20.87 ± 2.89; stretch group 22.47 ± 2.48 years) with decreased PSLR ROM, otherwise apparently healthy.	60 patients (mixed males and females – number not specified) with decreased AKE ROM, otherwise apparently healthy.
Interventions Investigated	NDS Group: Supine with neck/thoracic flexion. Hip/knee flexion alternated with hip/knee extension. Perform for 180 seconds. Stretching Group: Supine, PSLR hamstring stretch. Perform 5x30 seconds. Placebo Group: Supine with passive intrinsic foot joint mobilization.	NDS Group: Seated slump position (no overpressure) with active cervical and knee flexion/ankle plantarflexion alternated with cervical and knee extension/ankle dorsiflexion. Perform 5x60 seconds with 15sec rest for three days over one week period. Stretching Group: Modified hurdler's position with flexion at hip. Hold for 30sec three days over one week period.	NDS Group: Seated slump position (overpressure by clinician) with passive knee extension/ankle dorsiflexion alternated with knee flexion. Perform 3x30 reps on 3 consecutive days. Stretching Group Hold-relax PNF (Supine with 10sec stretch, 6sec static hold/contract, 30sec stretch). Perform 3 reps on 3 consecutive days.
Outcome Measures	ROM using PSLR test	ROM using PSLR	ROM using AKE
Main Findings	Significant improvement in ROM in NDS and stretching groups compared to placebo ($p<0.001$). NDS group significantly greater improvements than stretching group ($p=0.006$).	Significant improvement in ROM in both groups ($p<0.001$). No difference between groups ($p=0.057$).	Significant improvement in ROM in both groups (p-value not reported). Stretching group significantly greater improvements than NDS group ($p=0.0435$).
Level of Evidence	1b	2b	2b
Validity Score	PEDro 7/10	PEDro 4/10	PEDro 4/10
Conclusion	Both static stretching and neurodynamics were effective, with neurodynamic treatment being the most effective method to increase ROM.	Range of motion improvements were not different between groups.	Both PNF stretching and neurodynamics were effective, with PNF stretching being the most effective method to increase ROM.

Abbreviations: PSLR = Passive Straight Leg Raise; AKE = Active Knee Extension; ROM = Range of Motion; PNF = Proprioceptive Neuromuscular Facilitation; NDS = Neurodynamic Sliders

Table 4.5 Results of PEDro scale

	Castellote-Caballero et al[6]	**Pagare et al[7]**	**Vidhi et al[5]**
1. Eligibility criteria specified (yes/no)	Yes	Yes	Yes
2. Subjects randomly allocated to groups (yes/no)	Yes	Yes	Yes
3. Allocation was concealed (yes/no)	Yes	Yes	No
4. Groups similar at baseline (yes/no)	Yes	Yes	Yes
5. Subjects were blinded to group (yes/no)	Yes	No	No
6. Therapists who administered therapy were blinded (yes/no)	No	No	No
7. Assessors were blinded (yes/no)	Yes	No	No
8. Minimum 85% follow-up (yes/no)	No	No	No
9. Intent to treat analysis for at least 1 key variable (yes/no)	No	No	No
10. Results of statistical analysis between groups reported (yes/no)	Yes	Yes	Yes
11. Point measurements and variability reported (yes/no)	Yes	No	Yes
Overall Score (out of 10)	7/10	4/10	4/10

Item 1 not included in overall score

References

Castellote-Caballero, Y., Valenza, M.C., Puentedura, E.J., Fernandez-de-las-Penas, C., & Albuquerque-Sendin, F. (2014). Immediate effects of neurodynamic sliding versus muscle stretching on hamstring flexibility in subjects with short hamstring syndrome. *J Sports Med*, 2014:e127471.

Coppieters, M.W. & Butler, D.S. (2008). Do 'sliders' slide and 'tensioners' tension? An analysis of neurodynamic techniques and considerations regarding their application. *Manual Therapy*, *13*:213-221.

Decoster, L.C., Cleland, J., Altieri, C., & Russell, P. (2005). The effects of hamstring stretching on range of motion: A systematic literature review. *J Orthop Sports Phys Ther*, *35*(6), 377-387.

Ebell, M.H., Siwek, J., Weiss, B.D., Woolf, S.H., Susman, J., Ewigman, B., & Bowman, M. (2004). Strength of recommendation taxonomy (SORT): A patient-centered approach to grading evidence in the medical literature. *J Am Board Fam Pract*, *17*(1):59-67.

Fox, M. (2006). Effect on hamstring flexibility of hamstring stretching compared to hamstring stretching and sacroiliac joint manipulation. *Clin Chiropr*, *9*(1):21-32.

Pagare V.K., Ganacharya, P.M., Sareen, A., & Palekar, T.J. (2014). Effect of neurodynamic sliding technique versus static stretching on hamstring flexibility in football players with short hamstring syndrome. *J Musculoskelet Res, 17*(02):1450009.

Shacklock, M. (1995). Neurodynamics. *Physiotherapy, 81*(1):9-16.

Vidhi, S., Anuprita, T., Asmita, K., Twinkle, D., Unnati, P., & Sujata, Y. (2014). Comparison of PNF Technique with NDS Technique for Hamstrings Tightness in Asymptomatic Subjects. *Indian J Physiother Occup Ther- Int J*, *8*(3):158-161.

Weppler, C.H., & Magnusson, S.P. (2010). Increasing muscle extensibility: A matter of increasing length or modifying sensation? *Physical Therapy*, *90*(3), 438–449.

Youdas, J. W., Krause, D. A., Hollman, J. H., Harmsen, W. S., & Laskowski, E. (2005). The influence of gender and age on hamstring muscle length in healthy adults. *Journal of Orthopaedic & Sports Physical Therapy*, *35*(4), 246–252.

CHAPTER 5

APPLIED CLINICAL RESEARCH

Hamstring Range of Motion Following Total Motion Release® Forward Flexion Trunk Twist Versus Sham Treatment (Appendix C and D)

Key points:

- Traditional evaluation and treatment techniques of apparent hamstring tightness (AHT) fail to consider alternative causative factors, such as neural drive or fascial restriction, when addressing movement dysfunction.
- The Total Motion Release® (TMR®) forward flexion trunk twist (FFTT) may effectively address the underlying neural or fascial causes of AHT by utilizing multi-planar movement at the trunk and lumbopelvic complex.
- Participants categorized with AHT significantly improved on measures of ROM immediately after a single treatment of the TMR® FFTT compared to a sham group.

Multisite research partners: Bobby Bonser, Christy Hancock, Bethany Hansberger, Rick Loutsch, Eric Stanford, Alli Zeigel

Abstract

Context: Hamstring tightness is a common condition typically treated by stretching interventions. Limited evidence exists to support the use of the Total Motion Release® (TMR®) forward flexion trunk twist (FFTT) as a holistic approach to resolving hamstring tightness.

Objective: To assess the immediate and short-term effects of the TMR® FFTT on measures of hamstring extensibility.

Design: Multisite randomized controlled clinical trial.

Setting: University athletic training clinics.

Patients or Other Participants: Sixty (34 male, 26 female) healthy, physically active individuals presenting with signs of AHT.

Intervention(s): Participants were randomized into one of two groups: (a) treatment (TMR® FFTT) group or (b) sham group.

Main Outcome Measure(s): Hamstring ROM was assessed using the active knee extension (AKE), passive straight leg raise (PSLR), finger to floor distance (FFD), and v-sit and reach (VSR) tests. All measures were performed at baseline, immediately post-treatment, and at one day follow-up. Repeated measures ANOVAs were utilized to assess both within group and between groups differences. Holm's sequential Bonferroni corrections were performed to determine differences between groups. Statistical significance was considered at $p<.05$

Results: The TMR® FFTT group demonstrated significantly more improvement in ROM than the sham group immediately post-treatment for the AKE-Most Restricted (MR) (6.4° ± 4.8° vs. 2.7° ± 6.6°, p = 0.018, Cohen's d = 0.65, 95% CIs: 0.66°, 6.8°), PSLR-MR (5.8° ± 4.2° vs. 2.2° ± 4.5°, p = 0.002, Cohen's d = 0.85, 95% CIs: 1.7°, 6.4°), FFD (4.6cm ± 3.4cm vs. 2.0cm ± 4.1cm, p = 0.01, Cohen's d = 0.73, 95% CIs: 0.67cm, 4.7cm), and VSR (4.4cm ± 3.1cm vs. 1.7cm ± 2.9cm, p = 0.001, Cohen's d = 0.92, 95% CIs: 0.93cm, 4.0cm). No between-group differences were found at the one day follow-up.

Conclusions: The TMR® FFTT effectively increased ROM on measures of hamstring extensibility immediately following a single intervention compared to a sham treatment that consisted of a sub-optimal form of static stretching. In an effort to promote clinical relevance and increase external validity, the methodology of the study featured materials and methods readily available in athletic training clinics; however, limitations of the study may have hindered the magnitude of effect identified in the results. Future researchers should consider more stringent inclusion criteria and the response of various ROM measures following TMR® FFTT treatment.

Key Words: Regional interdependence, hamstring, tightness, stretching

Introduction

Hamstring tightness, commonly defined as a lack of hip flexion range of motion (ROM) with a concomitant feeling of restriction in the posterior thigh, has been documented across all age groups as a potential problem leading to dysfunctional or restricted movement.[1–9] The term hamstring tightness denotes that a lack of hip flexion or knee extension ROM is due to a tissue length deficit; however, researchers have drawn attention to multiple causal factors such as neural tension,[10–13] fascial restriction,[14] lumbopelvic dysfunction,[15,16] and/or joint or tissue length restrictions[17–20] that may contribute to this lack of ROM or tissue extensibility. Thus, the term apparent hamstring tightness (AHT) may be a better descriptor of the hamstring tightness phenomenon because the underlying cause may not be related to tissue length, and immediate gains in hamstring extensibility may be experienced following an intervention that does not address a tissue length deficit.

Tissue length deficits have been proposed to result from deformation in the elastic or plastic regions of connective tissue, leading to restricted joint motion.[19,21,22] Traditionally, AHT has been assessed using tests thought to measure the length of the hamstring muscle tissue, such as the active knee extension (AKE),[10,23–26] passive straight leg raise (PSLR),[27–31] finger to floor distance (FFD),[32] and sit and reach (SR)[33] tests. Likewise, treatment techniques commonly used for AHT were focused directly on muscle tissue (e.g., length changes) and include static, proprioceptive neuromuscular facilitation (PNF), and dynamic stretching.[34,35] Researchers have postulated that a stretching intervention may change tissue length due to the properties of viscoelastic deformation, plastic deformation, sarcomere adaptation, and neuromuscular relaxation.[21,22] The variance in repetitions, frequency, and duration of stretch protocols has led to inconsistent efficacy throughout the literature,[36–38] resulting in a lack of consensus regarding the most effective stretching protocol.

In light of the questionable efficacy and appropriateness of stretching to treat AHT, clinicians have been encouraged to rethink the classical approach to addressing AHT and consider factors other than tissue length deficits that may contribute to the perceived tightness.[39] Researchers examining alternative treatments involving more comprehensive movement patterns and lumbopelvic exercises have demonstrated promising results for increased knee ROM[40] and prevention of recurrent hamstring strain.[16] One novel technique that has yet to be studied extensively is Total Motion Release® (TMR®), a treatment philosophy based on regional interdependence in which the clinician assesses and treats imbalances throughout the body.

The regional interdependence theory is the idea that dysfunction or pain perceived in one area of the body may be influenced by a dysfunction or restriction in the neural, musculoskeletal, or fascial systems, amongst others.[41,42] A specific TMR® intervention, the TMR® forward flexion trunk twist (FFTT), has been proposed to treat AHT.[43,44] While the TMR® FFTT lacks a direct focus on lengthening hamstring musculature, improvements in both active hip flexion and knee extension ROM have been demonstrated after performing the technique.[44] Despite the paucity of research conducted on the TMR® FFTT, the technique may be a beneficial intervention for patients categorized with AHT. Therefore, the purpose of this study was to assess the immediate and short-term effects of the TMR® FFTT compared to a sham group on measures of hamstring ROM among healthy, physically active individuals presenting with signs and symptoms of AHT.

Methods

Participants

Participants were recruited from five different research sites across the country [athletic training clinics and student bodies at universities (2 NCAA Division I, 1 NCAA Division II, 1 NCAA Division III, and 1 NAIA)]. Physically active was defined as performing physical activity for at least 150 minutes a week or an average of 30 minutes a day five days per week.[35] Participants were active in a variety of settings (36 intercollegiate, 22 recreational, and 2 club sports) with the most common sports after recreational activity (22) being soccer (9), baseball (6), and track/field (6). A total of 70 physically active individuals (35 men: 20.8 ± 1.7 years; 35 women: 20.4 ± 1.4 years) volunteered to participate in this multisite research study and were screened for the following inclusion criteria: AKE angle of at least 20°, a TMR® FFTT asymmetry of at least 5 points, and a score of at least 1 on the Perceived Tightness Scale (PTS). The AKE was performed bilaterally and the leg with the most restricted motion was identified as the "most restricted" (MR) leg for ROM measurements throughout the study.

The following exclusion criteria were applied: (1) lower extremity injury in the previous six weeks; (2) lumbar pathology including back injury in the previous six weeks, known lumbar spine pathology limiting ROM (e.g., discogenic), prior lumbar spine surgical procedures, known lumbosacral spine physical impairments limiting ROM and function; (3) lower extremity surgery within last six months; major ligamentous surgery within last one year; (4) vestibulocochlear disturbances/concussion (5) joint hypermobility syndrome (Beighton Score of four or higher); (6) connective tissue disorders (e.g., Marfans, Ehlos Danlos); or (7) lower extremity neurovascular pathology, including numbness, tingling, and loss of sensation. A total of 10 participants were excluded from the study. One participant did not meet the physically active requirement; two participants had bilateral AKE angle measurements of less than 20°; five participants did not have a TMR® FFTT asymmetry; one participant reported low back pain; and one participant reported a lower extremity injury in the prior six weeks.

In total, 60 participants met the inclusion/exclusion criteria; 30 were randomly assigned to the TMR® FFTT group (20.7 ± 1.7 years; 42.3° ± 7.9° AKE-MR; 35.3 ± 20.1 TMR® asymmetry) and the other 30 were assigned to the sham group (20.6 ± 1.5 years; 45.1° ± 10.1° AKE-MR; 27.6 ± 17.8 TMR® asymmetry) (Table 5.1). Dropout criteria determined *a priori* included pain that developed during treatment; verbal request by participant to discontinue the study; and non-compliance (i.e., failure to return for one-day follow-up testing). Based on these criteria, two of the 60 participants dropped out of the study due to pain during the treatment (1) and noncompliance (1), leaving a total of 58 participants (TMR® FFTT = 28, sham = 30) who completed all stages of the study.

Prior to beginning the study, the research procedures were explained to each participant. All participants provided written consent to participate in this study and the study was approved by the Institutional Review Board of XXXXXX along with the Institutional Review Board at each of the five research sites.

Experimental Procedures

The principal investigators (n = 5) administered all ROM measurements and interventions at their respective sites. Prior to initiating the study, the clinicians completed the TMR® training courses and conducted a pilot study to validate their methods and establish consistency of treatments and measurements. To ensure measurement reliability amongst all clinicians participating in this multisite research study, the intra-rater and inter-rater reliabilities of the AKE, PSLR, FFD, and v-sit and reach (VSR) were assessed prior to beginning this study. All measurements had high intra-rater and inter-rater reliability assessed with Intraclass Correlation Coefficients (ICC) (3,1), with absolute agreement (Table 5.2).[45] The high reliability was consistent with the intra- and inter-rater values reported in the literature for the AKE,[23,31,46,47] PSLR,[46,48] FFD,[32] and VSR.[49] The standard error of measurement (SEM) and minimal detectable change (MDC) values were also calculated for each dependent variable from the reliability testing data performed prior to this study (Table 5.2). Standard measurement error was derived using the interrater ICC and the following formula: SEM=SD × √((1)-ICC).[50] Minimum detectable change for this study was subsequently calculated using the formula MDC=1.96 × √2 × SEM (Tables 5.2 - 5.3).[50]

Group allocation of the participants was concealed from the clinician until after baseline measurements were taken, at which point group assignment was revealed by opening a sealed, opaque envelope containing the participant’s group assignment. All baseline measurements were performed in a pre-determined, randomized order using a random number generator (random.org) without a rest period between measurements. After baseline measurements, participants completed the treatment intervention according to their group assignment. Following the intervention, immediate post-treatment and one day follow-up measurements were recorded in the same order as baseline measures.

Total Motion Release® (TMR®) Forward Flexion Trunk Twist (FFTT) Treatment

The TMR® FFTT treatment intervention began with a screening procedure by having the participant stand with feet together and arms crossed in front of the chest. The participant was instructed to flex forward at the waist into a neutral position or just prior to the point of discomfort (Figure 5.1a) and then twist to the right, return to the neutral position and then twist to the left. The participant was shown a TMR® grading scale (0-100) in which a score of zero equals “no problems at all” and a score of 100 equals “the worst” in regards to how the motion felt (i.e., pain, tightness, ROM, strength, tension, nervousness, and quality). The participant was asked to score the difference between twisting to the right versus twisting to the left by identifying a difficult side and indicating a percent difference between the difficult and easy sides. For the feet apart position, the participant was asked to stand with feet apart, flex forward at the waist over the right leg (Figure 5.2a), return to the starting position, and then flex forward at the waist over the left leg noting which leg “felt better” to flex forward over (i.e., the good leg). Following this, the participant forward flexed at the waist over the leg that “felt worse” and twisted towards midline, returned to the neutral position over the “bad leg,” and then twisted away from midline. The participant then identified which direction was more difficult and scored the motion in the same way as described above for the feet together position.

Following the screening procedure, each participant in the TMR® FFTT group performed two sets of 10 repetitions of the feet together FFTT to the side previously identified as the “easy side” during the screening procedure.[44,51] After twisting, the participants were instructed to slowly release anything felt to be preventing further movement (e.g., bending the knee, extending the trunk, looking over the shoulder) which would allow for further twisting motion with each repetition (Figure 5.1b). The participant was given 30 seconds to rest between sets. Following the TMR® FFTT treatment with feet together, the participant repeated the same procedure with feet apart, twisting in the “more difficult” direction over the good leg, as identified in the screening procedure (Figure 5.2b).[51]

The participant performed two sets of 10 repetitions in the feet apart position with the same "twist and then release" instructions provided. Immediately following the TMR® FFTT treatment, all participants completed post-treatment measurements.

Sham Treatment

The sham treatment required each participant to maintain a position of forward trunk flexion, without the twisting motion present in the TMR® FFTT, simulating a position often utilized in static stretching. Each participant randomized into the sham treatment group was instructed to stand with the feet together and arms crossed in front of the chest. The participant was then instructed to forward flex at the waist to approximately 90° or just prior to the point of discomfort to ensure that maximal, end-range stretching was avoided (Figure 5.1a). Each participant held this position for 30 seconds and then returned to the starting position. A total of four repetitions with 30 second holds were performed and 30 seconds of rest was provided between each repetition. Immediately following the sham treatment, all participants completed post-treatment measurements.

Range of Motion Measurement Methods

An inclinometer application (Clinometer, https://www.plaincode.com/products/clinometer/) was installed on an iPhone or Android smartphone device by each researcher. The Clinometer application was utilized to collect the AKE and PSLR measures and was calibrated before each participant's arrival. While not utilized in the lower extremity literature, the Clinometer application has been found to be reliable for measuring shoulder ROM [ICC (2,1) = .8].[52] Prior to collecting ROM measurements, a mark was placed on the anterior tibia (three inches below the tibial tuberosity) and on the anterior thigh (six inches above the tibial tuberosity) of each leg for all participants to ensure accurate and consistent placement of the smartphone for use of the Clinometer app. A cloth tape measure was used for the FFD and VSR tests. For all tests requiring unilateral measurements (AKE, PSLR), the right leg was assessed first, followed by the left leg. A total of three measurements were taken for all tests and the average of the three was reported, with the exception of the VSR, in which the third measure stood as the final score.[53]

Active Knee Extension (AKE) Measurement

The AKE was measured by the clinician with the participant in a supine position with one leg in a 90-90 position as an assistant stabilized the contralateral leg in an extended position (Figure 5.3a). The clinician placed one hand on the posterior thigh four inches superior to the knee while the other hand placed the smartphone inclinometer on the participant's anterior thigh with the top of the phone in line with the marking on the participant's thigh to assess maintenance of 90-degree positioning. The participant was then instructed to actively extend the knee to the point of discomfort, while maintaining 90 degrees of hip flexion. When the participant reached the point of discomfort (i.e., an uncomfortable amount of tension),[54] the clinician relocated the smartphone inclinometer from the anterior thigh to the mark at the mid-anterior tibia, making sure to keep the other hand on the posterior thigh to maintain 90 degrees of hip flexion (Figure 5.3b).

Passive Straight Leg Raise (PSLR) Measurement

The PSLR was measured by the clinician as the participant lay supine with the legs extended. The clinician passively flexed the participant's hip while maintaining knee extension and monitoring for pelvic rotation until the point of discomfort was reached. An assistant stabilized the contralateral leg in an extended position during the procedure (Figure

5.4). The ROM measurement was recorded with the smartphone inclinometer placed at the mark on the thigh.

Finger to Floor Distance (FFD) Measurement

The FFD test was performed with the participant standing on a 20 cm box with the feet together and the toes positioned at the edge of the box. The participant flexed at the waist with hands on top of one another, reaching for the toes, and stopping at the point of discomfort (Figure 5.5). The clinician visually ensured the participant’s knees did not flex while performing the movement. The clinician measured from the top edge of the box to the tip of the middle finger of the top hand in centimeters. A measurement of “0” indicated the fingertip was in line with the edge of the box. A positive number indicated that the fingers had not reached the edge of the box, while a negative number indicated the fingers were past the edge of the box. Measurements were rounded to the nearest half centimeter.

V-Sit and Reach (VSR) Measurement

A cloth tape measure was affixed to the floor using pieces of tape to assess the participant’s ROM. A piece of tape denoting the baseline “zero” point was placed at the 40 cm mark of the cloth tape measure. On the baseline tape strip, two marks were placed 15 cm on either side of the tape measure to denote the spot where the participant’s feet would be placed (Figure 5.6).

The participant was instructed to sit on the floor with the legs extended, the feet spaced 30 cm apart, and the plantar surface of the feet touching a box to keep the ankle joints in a neutral position.[53] An assistant stabilized one leg on the floor in an extended position, while the clinician stabilized the other leg. The participant placed one hand over top of the other and flexed at the waist towards the toes to the point of discomfort. The motion was performed three times and the measurement was taken on the third attempt. The clinician measured from the edge of the baseline “zero” tape line to the tip of the middle finger. A measurement of “0” indicated the fingertip was in line with the edge of the baseline “zero” tape line. A negative number indicated that the fingers had not reached the edge of the line, while a positive number indicated the fingers were past the edge of the line. Measurements were rounded to the nearest half centimeter.

Perceived Tightness Scale (PTS)

The participant’s perception of tightness was identified using the Perceived Tightness Scale (PTS) which was adapted from the 0-10 numeric rating scale (NRS). The NRS is a numerical ranked scale that measures the intensity of the participant’s pain;[55] however, in this study, the participants were asked to rate their amount of perceived hamstring tightness at baseline, immediately following the treatment, and at one day follow-up. On the PTS, a score of 0 indicated “no perceived tightness” and a score of 10 indicated “extreme tightness.”

Data Analysis

Statistical analysis was performed using SPSS statistical software (version 23; SPSS Inc., Chicago, IL). Each dependent variable was assessed for outliers by treatment group using estimates of skewness and kurtosis, visual inspection through histograms, as well as with Levene’s test and the Shapiro-Wilk test. One-way within subject repeated measures analysis of variance (RM-ANOVAs) were performed to assess the effect of the TMR® FFTT on each dependent variable over time. Bonferroni comparison testing was used for post-hoc analysis. Significance was considered to be $p \leq .05$. Between-groups effects were assessed using RM-ANOVAs for each dependent variable. Independent sample t-tests were used to assess between group differences at each time point (baseline-post treatment; baseline-one day follow-up). A Holm's sequential Bonferroni correction was performed to establish new alpha levels (i.e., .025, .05) for significant findings. Differences at baseline were assessed using independent t-tests; if a baseline difference was discovered, the variable was assessed using an independent t-test on the difference scores rather than with the RM-ANOVA. To determine the treatment effect size, the Cohen’s d statistic was calculated, with small ≥ .2, medium ≥ .5, and large ≥ .8.[56]

Effect size indicates the magnitude of difference between two groups, with moderate to large differences associated with increased clinical meaningfulness of the results.[56] Additionally, a conservative Holm’s sequential Bonferroni adjustment results in a decreased risk of Type I error, but also results in low power.[57] Low statistical power is associated with an increased risk of making a Type II error.[58] Therefore, our conservative statistical choices reduce the risk of incorrectly concluding the two groups are statistically different when they actually are not, but the tests may not have the power needed to detect differences that exist.[57]

Results

Active Knee Extension (AKE) - Most Restricted (MR) Leg

There were no differences at baseline in AKE-MR measurements ($t_{(56)}$ = -0.93, p = .354, 95% CIs: -7.0°, 2.5°) between TMR® FFTT (42.9° ± 7.7°) and sham treatment (45.1° ± 10.1°). The between-subjects time*group interaction was significant (λ = 0.9, $F_{(2,55)}$ = 3.21, p = .048, partial eta squared = 0.1, power = 0.59) (Table 5.4). Utilizing the Holm’s sequential Bonferroni adjustment for follow-up testing, there was a significant difference between TMR® FFTT (mean difference = 6.4° ± 4.8°) and sham treatment (mean difference = 2.7° ± 6.6°) immediately post-treatment ($t_{(56)}$ = 2.43, p = .018, Cohen’s d = 0.65, 95% CIs: 0.66°, 6.8°). There were no significant differences between groups at one day follow up ($t_{(56)}$ = 1.65, p = .105, Cohen's d = 0.44, 95% CIs: -0.53°, 5.5°).

The within-subjects time main effect for the TMR® FFTT group was significant (λ = 0.31, $F_{(2,26)}$ = 29.11, p < .001, partial eta squared = 0.69, power = 1.0) (Table 5.5). Bonferroni post-hoc testing revealed a significant increase in ROM from baseline to post-treatment (mean difference = 6.4°, SEM = 0.91°, p < .001) and from baseline to one day follow-up (mean difference = 5.0°, SEM = 1.1°, p < .001). Between time points within the TMR® FFTT group, participants maintained 79% of their post-treatment changes at the one day follow up for the AKE.

Passive Straight Leg Raise (PSLR) - Most Restricted (MR) Leg

There were no significant differences at baseline in PSLR-MR measurements ($t_{(58)}$ = -1.95, p = .056, 95% CIs: -15.8°, 0.2°) between TMR® FFTT (51.6° ± 14.8°) and sham treatment (59.0° ± 14.1°). The between-subjects time*group interaction was significant (λ = 0.85, $F_{(2,55)}$ = 4.98, p = .01, partial eta squared = 0.15, power = 0.79). Following the post-hoc assessment, a significant difference between TMR® FFTT (mean difference = 5.8° ± 4.2°) and sham treatment (mean difference = 2.2° ± 4.9°) was identified immediately post-treatment ($t_{(58)}$ = 3.2, p = .002, Cohen's d = 0.85, 95% CIs: 1.6°, 6.0°). There were no significant differences between groups at one day follow up ($t_{(56)}$ = 1.6, p = .115, Cohen's d = 0.43, 95% CIs: -0.86°, 7.7°).

The within-subjects time main effect for the TMR® FFTT group was significant (λ = 0.34, $F_{(2,26)}$ = 25.32, p < .001, partial eta squared = 0.66, power = 1.0). Bonferroni post-hoc testing revealed a significant increase in ROM from baseline to post-treatment (mean difference = 5.8°, SEM = 0.8°, p < .001) and from baseline to one day follow-up (mean difference = 4.4°, SEM = 1.5°, $p = .023$). Between time points within the TMR® FFTT group, participants maintained 76% of their post-treatment changes at the one day follow up for the PSLR.

Finger to Floor Distance (FFD)

Outlier assessment revealed a skewness value of 1.11 (SE = 0.43) with a kurtosis value of 2.16 (SE = 0.83) for the sham group at baseline. Histogram, box plot, and visual inspection of the data revealed two possible outliers; data for the FFD was removed for these participants prior to further analysis. Following outlier removal, skewness for the baseline FFD was -0.199 (SE = 0.44) and kurtosis was -1.05 (SE = 0.86). There was a significant difference at baseline in FFD measurements ($t_{(56)} = 2.48$, $p = .016$, 95% CIs: 1.2cm, 11.2cm, power = 0.57) between TMR® FFTT (10.5 cm ± 10.5 cm) and sham treatment (4.3 cm ± 8.1 cm). Independent sample t-tests were used and revealed a significant difference between TMR® FFTT (4.6 ± 3.4cm) and sham treatment (2.0 ± 4.1cm) immediately post-treatment ($t_{(54)} = 2.67$, $p = .01$, Cohen's d = 0.73, 95% CIs: 0.67 cm, 4.7 cm). There were no significant differences between groups at one day follow up ($t(54) = 1.4$, $p = .155$, Cohen's d = 0.39, 95% CIs: -0.73 cm, 4.5 cm).

The within-subjects time main effect for the TMR® FFTT group was significant ($\lambda = 0.34$, $F_{(2,26)} = 25.64$, $p < .001$, partial eta squared = 0.66, power = 1.0). Bonferroni post-hoc testing revealed a significant increase in ROM from baseline to post-treatment (mean difference = 4.6 cm, SEM = 0.64 cm, $p < .001$) and from baseline to one day follow-up (mean difference = 2.9 cm, SEM = 0.87 cm, $p = .008$). Between time points within the TMR® FFTT group, participants maintained 63% of their post-treatment changes at the one day follow up for the FFD.

V-Sit and Reach (VSR)

There were no differences at baseline in VSR measurements ($t_{(58)}$ = -0.9, p = .374, 95% CIs: -7.4 cm, 2.8 cm) between TMR® FFTT (-13.5 cm ± 11.0 cm) and sham treatment (-11.2 cm ± 8.3 cm). The between-subjects time*group interaction was significant (λ = 0.81, $F_{(2,55)}$ = 6.3, p = .003, partial eta squared = 0.19, power = 0.88). Post-hoc testing using independent t-tests and a Holm's sequential Bonferroni adjustment revealed a significant difference between TMR® FFTT (4.4 cm ± 3.1 cm) and sham treatment (1.7 cm ± 2.9 cm) immediately post-treatment ($t_{(58)}$ = 3.45, p = .001, Cohen's d = 0.92, 95% CIs: 1.1 cm, 4.3 cm). There were no significant differences between groups at one day follow up (t(56) = 2.0, p = .054, Cohen's d = 0.53, 95% CIs: -0.04 cm, 4.6 cm).

The within-subjects time main effect for the TMR® FFTT group was significant (λ = 0.3, $F_{(2,26)}$ = 31.018, p < .001, partial eta squared = 0.71, power = 1.0). Bonferroni post-hoc testing revealed a significant increase in ROM from baseline to post-treatment (mean difference = -4.4 cm, SEM = 0.6 cm, p < .001) and from baseline to one day follow-up (mean difference = -2.2 cm, SEM = 0.6 cm, p = .005). Between time points within the TMR® FFTT group, participants maintained 49% of their post-treatment changes at the one day follow up for the VSR.

Perceived Tightness Scale (PTS)

Outlier assessment revealed no significance at baseline for either the TMR® FFTT group (Shapiro-Wilk = 0.93, p = .068) or the sham group (Shapiro-Wilk = 0.97, p = .591). The non-parametric Mann Whitney U was not significant for baseline (U = 368.5, p = .417), immediate post-treatment (U = 332, p = .162) or one day follow-up (U = 337.5, p = .194).

Discussion

In this exploratory study, the TMR® FFTT produced significant improvements in ROM on the AKE, PSLR, FFD, and VSR to a greater extent than the sham treatment immediately following a single session. No significant differences were found to suggest the TMR® FFTT had an effect on ROM measures greater than the sham treatment at a one day follow-up. Although statistically significant gains in ROM were produced, further analysis of the data highlighted the clinical meaningfulness of the results. Moderate (0.65) to large (0.92) Cohen's *d* effect sizes were identified post-treatment, suggesting the TMR® FFTT treatment was clinically relevant with a moderate to large effect on ROM immediately following treatment.

The clinical relevance of this study is also enhanced due to the methodological decisions and a focus on external validity. For example, all participants were active individuals with complaints of AHT who presented to clinicians within collegiate athletic training clinics, with each ROM measurement completed utilizing methods and materials commonly located within clinics. Additionally, the Clinometer application used to record ROM is available for both Android and iPhone users. While participants were asked not to change their activity level during the study, their outside activities were not controlled between the immediate post-treatment measurements and the one day follow-up measurements by the clinicians at any of the five research sites. Therefore, the effects of a single treatment of TMR® FFTT after one day must be interpreted with caution due to the potential for confounding variables as well as the large standard deviations associated with the baseline-one day calculations.

Although the immediate results of the TMR® FFTT were statistically significant, the gains in ROM the participants experienced were moderate by clinical standards on all measures. One explanation for why the gains in ROM were not greater may be that participants were only required to present with restricted ROM on the AKE to be included. As a result, several participants were included who did not display restrictions in ROM on the PSLR (TMR® FFTT = 2, Sham = 3), FFD (TMR® FFTT = 7, Sham = 9), or VSR (TMR® FFTT = 4, Sham = 5). In addition, the lack of restriction in ROM on the PSLR, FFD, and VSR may have contributed to the low percentage (0%, 9.5%, and 2%, respectively) of individuals who achieved functional levels of ROM on each measure immediately following treatment. Although in this preliminary study, the TMR® FFTT demonstrated only moderate results immediately following treatment and no changes after one day, the technique has been explored in other research.

The inclusion of the TMR® FFTT as a regionally interdependent treatment for AHT is supported in the literature in the form of a case study in which the patient gained 20°-30° on the AKE after a single TMR® FFTT treatment.[44] A possible explanation for the greater gains in ROM on the AKE compared to our study is that the case described by Baker et al.[44] featured a patient with a history of lumbar spine pathology with chronic AHT symptoms (over 5 years), and a large TMR® FFTT asymmetry at initial exam. Additionally, the patient’s baseline AKE measurements were 13-17° more restricted than the average baseline AKE in our study, which may contribute to the greater gain in ROM achieved on the AKE following a single treatment. Although the patient’s changes in AKE ROM were different from our findings, her changes on the SR (4.9cm) were similar to our results for the VSR (4.2cm). The VSR results may be more similar to the SR as both assessments require attention not only to isolated tissue tension, but also to the lumbopelvic and thoracic movements that occur with active trunk flexion. Likewise, increases in hamstring extensibility have been demonstrated on other measures (e.g., AKE, PSLR) with the application of regionally interdependent treatments focused on joint mobility[59,60] and the nervous system.[61]

Similar to the TMR® FFTT, the Mulligan Concept and neurodynamics are treatment paradigms demonstrated to address AHT through a regionally interdependent approach. Neural tension[10,13] and lumbopelvic dysfunction may result in restricted extensibility by creating a perception of hamstring tightness. Treatment of the lumbopelvic complex through Mulligan Concept hip mobilizations with movement effectively increased ROM on the PSLR by 13°-17° in individuals classified with tight hamstrings.[59, 60] Additionally, neurodynamic sliders of the sciatic nerve have also been found to be significantly more effective (9.9° ± 2.5°, 95% CIs: 9.1°, 10.7°) than static stretching (5.5° ± 1.6°, 95% CIs: 5.0°, 6.0°, p=0.006) at improving hip flexion ROM on the PSLR.[61] Compared to the results of these studies, we observed a 5.8° increase in hip flexion ROM on the PSLR immediately following one treatment of the TMR® FFTT. Although the specific mechanism by which the TMR® FFTT affects AHT is unknown, the technique has been proposed to increase hamstring extensibility using the theories of neural coupling[62-64] and biotensegrity.[65] Aside from treatments with a holistic approach, stretching is perhaps the most common local treatment used for addressing AHT.

In several studies, static stretching of the hamstrings musculature has resulted in knee extension and hip flexion ROM gains.[24,36–38,66] DePino et al.[24] found a 5-6° improvement of knee extension ROM on the AKE after four consecutive 30-second static stretches. De

Weijer et al.[66] conducted a similar study, identifying a 13° increase in extensibility on the AKE using three 30-second hamstring stretches performed following a warm-up. In addition to a warm-up, variation in methodologies between the two studies include that participants in the De Weijer group were passively stretched in an AKE test position with an adjustment made to increase the stretch if the participant became acclimated after 15 seconds, while participants in the DePino study performed active stretching in a standing position with no adjustments. The TMR® FFTT resulted in gains in ROM on the AKE that were similar to the DePino study (6.4°), but not as drastic as the De Weijer study. The methodological variation in the De Weijer study may help to explain the increased ROM compared to both the DePino study and this study, neither of which included a warm-up or passive stretch with an adjustment for stretch tolerance. Within both the DePino et al. and De Weijer et al. studies, the gains lessened as time progressed, with decreases in motion occurring three[24] to 15 minutes[66] after the cessation of the stretching intervention. The duration of static stretching effect is conflicting in the literature, with return to baseline scores ranging from shortly after treatment to more than one day following treatment. Following the cessation of the stretch intervention, only 4.5% of the extensibility gains were maintained at nine minutes,[24] compared to other reports of 59% maintained after 24 hours.[66]

Although the TMR® FFTT group had statistically significant and clinically meaningful results in comparison to the sham group, the sham group also demonstrated gains in ROM on the AKE immediately post-treatment (2.7°±6.6°) and at a one day follow-up (2.6°±5.5°). A possible explanation for the ROM gains in the sham group is that the forward flexed position may have placed a low-grade static stretch on the musculotendinous and neural structures of the posterior chain. According to the sensory theory,[22] the application of a short-duration stretching technique may perpetuate an increase in stretch tolerance, producing ROM gains over time. Despite the sham group demonstrating gains in ROM and maintaining those gains at one day follow-up, the relatively small ROM gains are within the SEM on the AKE (3.28°) and are likely not clinically meaningful.

In the current study, all participants were identified to have an asymmetry based on the TMR® FFTT evaluation, which may aid in identifying the underlying factors of AHT beyond tissue length deficits. Traditional evaluation of AHT accounts for the joint and tissue length restriction via assessments that include the AKE and PSLR, leading to treatment choices such as stretching. By incorporating a regionally interdependent approach to evaluation, such as the TMR® FFTT, clinicians may be able to more effectively classify patients and provide treatments that address alternative causal factors perpetuating AHT. Therefore, we propose that clinicians should utilize a holistic assessment that guides clinical decision making and treatment selection based on exam findings for patients with AHT.

Limitations and Future Research

Several methodological choices resulted in procedural limitations in this study, including: (a) the multi-site nature of the study, with multiple raters assessing ROM; (b) the decision to focus on a sham comparison versus a direct comparison to an established treatment; (c) no blinding of the clinician occurred in this study; (d) only the AKE was utilized as an inclusion method; (e) the outside activities of the participants were not controlled; (f) each ROM measure was assessed consecutively, with no rest in between. Other limitations include that the results of this study may not be generalized to a population outside of a healthy, young, active group of participants with restricted hamstring extensibility on an AKE assessment. As the focus of this study was on short-term efficacy of a single treatment, implications for long-term results of the TMR® FFTT, or the TMR® system, may not be derived from this study. Additionally, the clinicians providing treatment were relative novices using TMR®, practicing the paradigm for just less than two years.

Future investigators may wish to set more stringent inclusion criteria to determine a more accurate presentation of the treatment's effect on participants who present with restrictions on multiple measures of hamstring extensibility. Similarly, it may be beneficial to identify how AHT varies across the different assessment methods and how each method responds to TMR® FFTT treatment. Furthermore, future studies should be conducted to examine the most effective method of implementing the TMR® FFTT protocol (e.g., feet together or feet apart first).

Conclusion

The current study represents the preliminary exploration of the effects of the TMR® FFTT on patients with limited extensibility on the AKE. The TMR® FFTT is effective at increasing ROM on measures of hamstring extensibility immediately following a single intervention compared to a sham treatment that consisted of a sub-optimal form of static stretching. Despite the many limitations of this study, the outcomes support that the TMR® FFTT may be a promising alternative intervention to the traditional methods, however, further investigation is needed to support this hypothesis.

Table 5.1. Demographic data for included participants at baseline (N=58).

	TMR® FFTT	**Sham**
Gender	13 F, 15 M	13 F, 17 M
Age	20.8 ± 1.7	20.6 ± 1.5
AKE (most restricted leg)	42.9º ± 7.7º	45.1º ± 10.1º
TMR® Asymmetry	36.1 ± 20.2	27.8 ± 17.8
PTS Score	5.2 ± 2.0	5.8 ± 1.8
Population	17 IC, 0 CS, 11 REC	17 IC, 2 CS, 11 REC
AKE=active knee extension; PTS=Perceived Tightness Scale; TMR®=Total Motion Release® Activity Level: IC=intercollegiate; CS=club sport; REC=recreational		

Table 5.2. Inter-rater reliability data for all range of motion measurements.

Measurement	**Inter-Rater ICC**	**Inter-Rater 95% CI**	**SEM**	**MDC**
AKE	0.94	0.90, 0.97	3.28°	9.08°
PSLR	0.88	0.77, 0.94	6.88°	19.07°
FFD	0.98	0.96, 0.99	1.54 cm	4.26 cm
VSR	0.98	0.97, 0.99	1.40 cm	3.89 cm
AKE=active knee extension; CI=confidence interval; FFD-finger to floor distance; ICC=intraclass correlation coefficient; MDC=minimal detectable change; PSLR=passive straight leg raise; SEM=standard error of measurement; VSR=v-sit and reach				

Table 5.3. Intra-rater reliability data for all range of motion measurements.

Rater	AKE	PSLR	VSR	FFD
AZ				
ICC	0.879	0.871	0.95	0.959
SEM	4.31°	5.78°	2.33cm	1.92cm
MDC	11.95°	16.03°	6.46cm	5.31cm
BB				
ICC	0.8	0.889	0.957	0.935
SEM	5.42°	6.49°	2.18cm	2.56
MDC	15.02°	17.98°	6.05cm	7.11cm
BH				
ICC	0.894	0.914	0.951	0.949
SEM	4.30°	5.06°	2.28cm	2.16cm
MDC	11.92°	14.04°	6.31cm	5.98cm
CH				
ICC	0.867	0.872	0.943	0.947
SEM	4.33°	4.99°	2.47cm	2.13
MDC	12.01°	13.82°	6.86cm	5.89cm
RL				
ICC	0.861	0.902	0.965	0.954
SEM	4.86°	5.12°	1.88cm	2.00cm
MDC	13.47°	14.19°	5.22cm	5.55cm

AKE=active knee extension; CI=confidence interval; FFD-finger to floor distance; ICC=intraclass correlation coefficient; MDC=minimal detectable change; PSLR=passive straight leg raise; SEM=standard error of measurement; VSR=v-sit and reach

Table 5.4. Between-subjects effects of TMR® FFTT vs. sham over time.

	Pre-Post (mean difference ± SD)				Pre-One Day (mean difference ± SD)			
	TMR® FFTT	Sham	p-value	95% CI of difference	TMR® FFTT	Sham	p-value	95% CI of difference
Most restricted AKE	6.4°±4.7°	2.7°±6.6°	0.015*	0.74, 6.7	5.0°±6.0°	2.6°±5.5°	0.105	-0.53, 5.5
Least restricted AKE	3.0°±5.8°	0.33°± 5.5°	0.076	-0.29, 5.6	1.9°±5.6°	0.33°±5.3°	0.285	-1.3, 4.4
Most restricted PSLR	6.2°±4.6°	2.2°±4.5°	0.001*	1.7, 6.4	4.4°±8.1°	1.0°±8.1°	0.115	-0.86, 7.7
Least restricted PSLR	4.8°±5.8°	2.1°±6.7°	0.1	-0.53, 5.9	3.8°±7.8°	0.61°±10.2°	0.194	-1.6, 7.9
FFD	4.5±3.5 cm	2.0±4.1 cm	0.015*	0.5, 4.5	2.9±4.6 cm	1.0±5.1cm	0.155	-0.73, 4.5
VSR	4.2±3.1 cm	1.7±2.9 cm	0.002*	0.93, 4.0	2.2±3.3 cm	-0.12±5.2 cm	0.054	-0.04, 4.6

*Indicates significance using Holm's sequential Bonferroni post-hoc testing.
AKE=active knee extension; CI=confidence interval; FFD=finger-floor distance; PSLR=passive straight leg raise; TMR® FFTT= Total Motion Release® forward flexion trunk twist; VSR=v-sit and reach

Table 5.5. Within-subjects effects of TMR® FFTT over time (mean ± SD).

	Baseline	Immediate Post-Treatment	One-day Follow-up
Most Restricted AKE	42.9º ± 7.7º	36.5º ± 6.8º*	37.9º ± 10.2º*
Most Restricted PSLR	51.6º ± 14.8º	57.4º ± 15.2º*	56.0º ± 13.6º*
FFD	10.5cm ± 10.5cm	5.9cm ± 8.8cm*	7.6cm ± 11.4cm*
VSR	-13.5cm ± 11.0cm	-9.1cm ± 11.0cm*	-11.4cm ± 11.4cm*^

*Significant difference from baseline (p≤0.05)
^Significant difference from immediate post-treatment (p≤0.05)
AKE=active knee extension; FFD=finger-floor distance; PSLR=passive straight leg raise; VSR=v-sit and reach

Figure 5.1. Sham treatment (A only) and TMR® FFTT feet together position (A and B).

Figure 5.2. TMR® FFTT feet apart treatment.

Figure 5.3. Active knee extension (AKE) assessment.

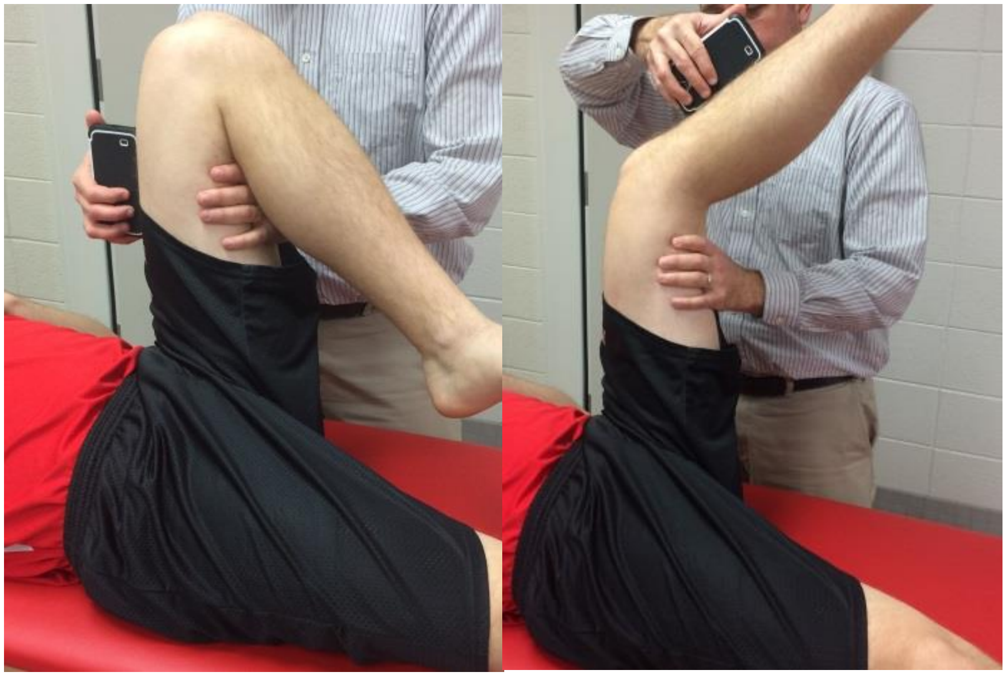


Figure 5.4. Passive straight leg raise (PSLR) assessment.

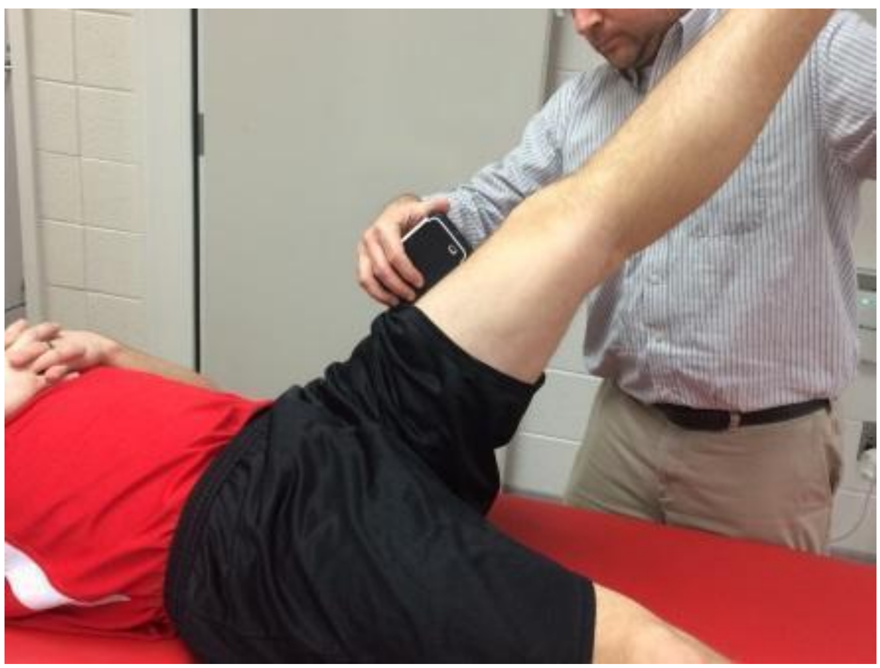
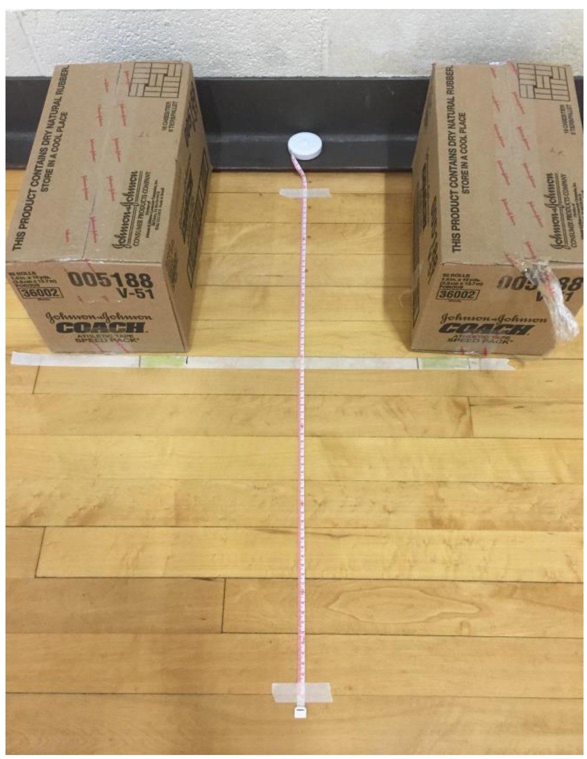


Figure 5.5. Finger to floor distance (FFD) assessment.

Figure 5.6. V-sit and reach (VSR) set-up.



References

1. Chandler TJ, Kibler WB, Uhl TL, Wooten B, Kiser A, Stone E. Flexibility comparisons of junior elite tennis players to other athletes. *Am J Sports Med*. 1990;18(2):134–136.

2. Gh ME, Alilou A, Ghafurinia S, Fereydounnia S. Prevalence of faulty posture in children and youth from a rural region in Iran. *Biomed Hum Kinet*. 2012;4.

3. Mangine RE, Noyes FR, Mullen MP, Barber SD. A physiological profile of the elite soccer athlete. *J Orthop Sports Phys Ther*. 1990;12(4):147-152.

4. Mollinger LA, Steffen TM. Knee flexion contractures in institutionalized elderly: Prevalence, severity, stability, and related variables. *Phys Ther*. 1993;73(7):437-444.

5. Brodersen A, Pedersen B, Reimers J. Incidence of short hamstrings and leg muscles at ages 3-17 years. *Ugeskr Laeg*. 1993;155(46):3764-3766.

6. Weerasekara I. The prevalence of hamstring tightness among the male athletes of University of Peradeniya in 2010, Sri Lanka. *Int J Phys Med Rehab*. 2013;01(01).

7. Worrell T, Perrin D. Hamstring muscle injury: The influence of strength, flexibility, warm-up, and tatigue. *J Orthop Sports Phys Ther*. 1992;16(1):12-18.

8. Youdas JW, Krause DA, Hollman JH, Harmsen WS, Laskowski E. The influence of gender and age on hamstring muscle length in healthy adults. *J Orthop Sports Phys Ther*. 2005;35(4):246–252.

9. Jóźwiak M, Pietrzak S, Tobjasz F. The epidemiology and clinical manifestations of hamstring muscle and plantar foot flexor shortening. *Dev Med Child Neurol*. 1997;39(7):481-483.

10. Kuilart KE, Woollam M, Barling E, Lucas N. The active knee extension test and Slump test in subjects with perceived hamstring tightness. *Int J Osteopath Med*. 2005;8(3):89-97.

11. Turl SE, George KP. Adverse neural tension: a factor in repetitive hamstring strain? *J Orthop Sports Phys Ther*. 1998;27(1):16-21.

12. McHugh M, Johnson C, Morrison R. The role of neural tension in hamstring flexibility. *Scand J Med Sci Sports*. 2012;22(2):164-169.

13. 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.

14. Schleip R, Findley TW, Chaitow L, Huijing P. *Fascia: The Tensional Network of the Human Body: The Science and Clinical Applications in Manual and Movement Therapy*. Elsevier Health Sciences; 2013.

15. Hoskins W, Pollard H. The effect of a sports chiropractic manual therapy intervention on the prevention of back pain, hamstring and lower limb injuries in semi-elite Australian Rules footballers: a randomized controlled trial. *BMC Musculoskelet Disord*. 2010;11(1):64.

16. Sherry MA, Best TM. A comparison of 2 rehabilitation programs in the treatment of acute hamstring strains. *J Orthop Sports Phys Ther*. 2004;34(3):116–125.

17. Goldspink G, Tabary C, Tabary JC, Tardieu C, Tardieu G. Effect of denervation on the adaptation of sarcomere number and muscle extensibility to the functional length of the muscle. *J Physiol*. 1974;236(3):733-742.

18. Tabary JC, Tabary C, Tardieu C, Tardieu G, Goldspink G. Physiological and structural changes in the cat's soleus muscle due to immobilization at different lengths by plaster casts. *J Physiol*. 1972;224(1):231-244.

19. Wessling KC, DeVane DA, Hylton CR. Effects of static stretch versus static stretch and ultrasound combined on triceps surae muscle extensibility in healthy women. *Phys Ther*. 1987;67(5):674-679.

20. Williams PE, Goldspink G. Changes in sarcomere length and physiological properties in immobilized muscle. *J Anat*. 1978;127(Pt 3):459-468.

21. Sapega AA, Quedenfeld TC, Moyer RA. Biophysical factors in range of movement exercise. *ResearchGate*. 1981;57:65.

22. Weppler CH, Magnusson SP. Increasing muscle extensibility: A matter of increasing length or modifying sensation? *Phys Ther*. 2010;90(3):438-449.

23. Cameron DM, Bohannon RW. Relationship between active knee extension and active straight leg raise test measurements. *J Orthop Sports Phys Ther*. 1993;17(5):257–260.

24. DePino GM, Webright WG, Arnold BL. Duration of maintained hamstring flexibility after cessation of an acute static stretching protocol. *J Athl Train*. 2000;35(1):56-59.

25. Mhatre BS, Singh YL, Tembhekar JY, Mehta A. Which is the better method to improve "perceived hamstrings tightness" – Exercises targeting neural tissue mobility or exercises targeting hamstrings muscle extensibility? *Int J Osteopath Med*. 2013;16(3):153-162.

26. Spernoga SG, Uhl TL, Arnold BL, Gansneder BM. Duration of maintained hamstring flexibility after a one-time, modified hold-relax stretching protocol. *J Athl Train*. 2001;36(1):44-48.

27. Ayala F, Sainz de Baranda P, De Ste Croix M, Santonja F. Absolute reliability of five clinical tests for assessing hamstring flexibility in professional futsal players. *J Sci Med Sport*. 2012;15(2):142-147.

28. Baker RT, Nasypany A, Seegmiller JG, Baker JG. Instrument-assisted soft tissue mobilization treatment for tissue extensibility dysfunction. *IJATT*. 2013;18(5):16-21.

29. Bohannon RW. Cinematographic analysis of the passive straight-leg-raising test for hamstring muscle length. *Phys Ther*. 1982;62(9):1269–1274.

30. Cameron DM, Bohannon RW, Owen SV. Influence of hip position on measurements of the straight leg raise test. *J Orthop Sports Phys Ther*. 1994;19(3):168–172.

31. Gajdosik R, Lusin G. Hamstring muscle tightness reliability of an active-knee-extension test. *Phys Ther*. 1983;63(7):1085-1088.

32. Perret C, Poiraudeau S, Fermanian J, Colau MML, Benhamou MAM, Revel M. Validity, reliability, and responsiveness of the fingertip-to-floor test. *Arch Phys Med Rehabil*. 2001;82(11):1566–1570.

33. Hui SS, Yuen PY. Validity of the modified back-saver sit-and-reach test: a comparison with other protocols. *Med Sci Sports Exerc*. 2000;32(9):1655-1659.

34. 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.

35. Garber CE, Blissmer B, Deschenes MR, et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334-1359.

36. Bandy WD, Irion JM, Briggler M. The effect of time and frequency of static stretching on flexibility of the hamstring muscles. *Phys Ther*. 1997;77(10):1090–1096.

37. Bandy WD, Irion JM, Briggler M. The effect of static stretch and dynamic range of motion training on the flexibility of the hamstring muscles. *J Orthop Sports Phys Ther*. 1998;27(4):295–300.

38. Davis DS, Ashby PE, McCale KL, Mcquain JA, Wine JM. The effectiveness of three stretching techniques on hamstring flexibility using consistent stretching parameters. *J Strength Cond Res*. 2005;19(1):27–32.

39. Kuszewski M, Gnat R, Saulicz E. Stability training of the lumbo-pelvo-hip complex influence stiffness of the hamstrings: a preliminary study: Stability training vs hamstring stiffness. *Scand J Med Sci Sports*. 2008;19(2):260-266.

40. Stephens J, Davidson J, DeRosa J, Kriz M, Saltzman N. Lengthening the hamstring muscles without stretching using "Awareness Through Movement." *Phys Ther*. 2006;86(12):1641-1650.

41. Sueki DG, Cleland JA, Wainner RS. A regional interdependence model of musculoskeletal dysfunction: research, mechanisms, and clinical implications. *J Man Manip Ther*. 2013;21(2):90-102.

42. Wainner R, Whitman J, Cleland J, Flynn T. Guest editorial. Regional interdependence: a musculoskeletal examination model whose time has come. *J Orthop Sports Phys Ther*. 2007;37(11):658-660.

43. Archuleta I, Helvey J, Baker R, MacDonald N. The acute effects of total motion release on lower extremity mobility deficits. April 2013.

44. Baker RT, Hansberger BL, Warren L, Nasypany A. A novel approach for the reversal of chronic apparent hamstring tightness: a case report. *Int J Sports Phys Ther*. 2015;10(5):723-733.

45. Streiner DL, Norman GR, Cairney J. *Health Measurement Scales: A Practical Guide to Their Development and Use*. Oxford University Press; 2014.

46. Davis DS, Quinn RO, Whiteman CT, Williams JD, Young CR. Concurrent validity of four clinical tests used to measure hamstring flexibility. *J Strength Cond Res*. 2008;22(2):583–588.

47. Reurink G, Goudswaard GJ, Oomen HG, et al. Reliability of the active and passive knee extension test in acute hamstring injuries. *Am J Sports Med*. 2013;41(8):1757-1761.

48. Gabbe BJ, Bennell KL, Wajswelner H, Finch CF. Reliability of common lower extremity musculoskeletal screening tests. *Phys Ther Sport*. 2004;5(2):90-97.

49. Cuberek R, Machova I, Lipenska M. Reliability of V sit-and-reach test used for flexibility self-assessment in females. *Acta Gymnica*. January 2013:35-39.

50. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res*. 2005;19(1):231–240.

51. Dalonzo-Baker T. *Getting Rid of Tight Hamstrings Quickly - The TMR Way - Part 2.*; 2012. https://www.youtube.com/watch?v=oCMnMpUlGHo. Accessed May 8, 2015.

52. Werner BC, Holzgrefe RE, Griffin JW, et al. Validation of an innovative method of shoulder range-of-motion measurement using a smartphone clinometer application. *J Shoulder Elbow Surg*. 2014;23(11):e275-e282.

53. Miñarro PAL, Andújar PS de B, García PLR, Toro EO. A comparison of the spine posture among several sit-and-reach test protocols. *J Sci Med Sport*. 2007;10(6):456-462.

54. Huang SY, Di Santo M, Wadden KP, Cappa DF, Alkanani T, Behm DG. Short-duration massage at the hamstrings musculotendinous junction induces greater range of motion. *J Strength Cond Res Natl Strength Cond Assoc*. 2010;24(7):1917-1924.

55. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: visual analog scale for pain (vas pain), numeric rating scale for pain (nrs pain), mcgill pain questionnaire (mpq), short-form mcgill pain questionnaire (sf-mpq), chronic pain grade scale (cpgs), short form-36 bodily pain scale (sf-36 bps), and measure of intermittent and constant osteoarthritis pain (icoap). *Arthritis Care Res*. 2011;63(S11):S240-S252.

56. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2 edition. Hillsdale, N.J: Routledge; 1988.

57. Verhoeven KJ, Simonsen KL, McIntyre LM. Implementing false discovery rate control: increasing your power. *Oikos*. 2005;108(3):643-647.

58. Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155.

59. Pratishtha K, Jagga V. Effect of mulligan stretching techniques (TSLR AND BLR) on biceps femoris muscle and pelvic rotation by using surface EMG and bubble inclinometer respectively. *J Exerc Sci Physiother*. 2012;8(1):39.

60. Yıldırım M, Ozyurek S, Tosun O, Uzer S, Gelecek N. Comparison of effects of static, proprioceptive neuromuscular facilitation and Mulligan stretching on hip flexion range of motion: a randomized controlled trial. *Biol Sport*. 2016;33(1):89-94.

61. Castellote-Caballero Y, Valenza MC, Puentedura EJ, Fernández-de-las-Peñas C, Alburquerque-Sendín F. Immediate effects of neurodynamic sliding versus muscle stretching on hamstring flexibility in subjects with short hamstring syndrome. *J Sports Med*. 2014;2014:1-8.

62. Huang HJ, Ferris DP. Neural coupling between upper and lower limbs during recumbent stepping. *J Appl Physiol*. 2004;97(4):1299-1308.

63. Huang HJ, Ferris DP. Upper and lower limb muscle activation is bidirectionally and ipsilaterally coupled. *Med Sci Sports Exerc*. 2009;41(9):1778.

64. Zehr EP, Loadman PM, Hundza SR. Neural control of rhythmic arm cycling after stroke. *J Neurophysiol*. 2012;108(3):891-905. doi:10.1152/jn.01152.2011.

65. Swanson R. Biotensegrity: A unifying theory of biological architecture with applications to osteopathic practice, education, and research—A review and analysis. *J Am Osteopath Assoc*. 2013;113(1):34-52.

66. 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):727-733.

APPENDIX A

TRANSFER OF COPYRIGHT FROM *INTERNATIONAL JOURNAL OF ATHLETIC THERAPY AND TRAINING*

Transfer of Copyright: ***International Journal of Athletic Therapy and Training***

Human Kinetics, Inc., P.O. Box 5076, Champaign, IL 61825-5076.

To be completed by the Corresponding Author

Author names (in order of authorship): Christy L Hancock, Bethany L Hansberger, Rick A Loutsch, Eric K Stanford
Alli K Zeigel, Robert J Bonser, Russell Baker, Scott Cheatham, James May, Alan Nasypany

Manuscript Title: Changes in Hamstring Range of Motion following Proprioceptive Neuromuscular Facilitation Stretching Compared with Static Stretching: A Critically Appraised Topic

Manuscript Number: ____________________
[To be completed by the editorial office]

Copyright is hereby transferred to Human Kinetics effective if and when the article is accepted for publication in the *International Journal of Athletic Therapy and Training*; if the manuscript is not accepted, the copyright reverts to the author(s). This transfer of copyright gives Human Kinetics the exclusive right to place the article in various electronic forms in addition to any printed journal. Those forms include, but are not limited to, publication in the journal's "in press" and final online versions on the journal's Web site and in various online databases.

These rights encompass the article in its entirety, including original tables, figures, and any supplementary material that may be part of the final published article. For authors who are employees of the U.S. Government, the transfer of copyright is understood to be effective only to the extent that such copyright is transferable.

The authors explicitly reserve the following rights:

- All proprietary rights other than copyright, such as patent rights.
- The right to use all or part of this article in future works of their own, such as dissertations, lectures, reviews, or textbooks.
- The right to make copies for their own teaching use.
- The right to use original figures and tables in future publications, provided explicit acknowledgment is made of their initial appearance in this journal.
- The right to post an electronic version of the final manuscript, as accepted for publication, on the authors' own Web site or Web site(s) or other electronic repositories controlled by the authors' institution, provided that the electronic version is in PDF or other image-capturing format. The posted version must contain the words "As accepted for publication in *International Journal of Athletic Therapy and Training*, ©Human Kinetics" and include the DOI link to the article or, if not DOI is available, a URL link to the article's abstract page.

Through signature below, the undersigned author (a) signifies acceptance of the terms and conditions listed above; (b) affirms that written permission has been obtained for all previously published and/or copyrighted material contained in this manuscript and any supplemental materials for print and online publication, as well as any other requisite permissions or releases, and that all such material has been clearly identified in the manuscript; (c) affirms that the manuscript is an original work of authorship that has not has not been previously published, does not infringe any third party's intellectual property rights, and does not contain any material that is defamatory or libelous; and (d) affirms that he/she is authorized to sign this form on behalf of all authors. (In the case of a work made for hire, the below may be signed by the employer.)

Christy L Hancock	4/20/2016
Signature	Date

FOR U.S. GOVERNMENT EMPLOYEES ONLY:
In lieu of the author signature above, author(s) whose work was performed within the scope of their employment with the U.S. Government must provide the signature of an authorized representative, certifying that the work is in the public domain. (If the work was performed under Government contract but the author is not a Government employee, no signature is required in this section.)

I certify that the majority of the authors or the primary authors of the manuscript cited above are employees of the U.S. Government and performed this work as part of their employment and that the paper is therefore not subject to U.S. copyright protection.

Signature and Title	Date

APPENDIX B

TRANSFER OF COPYRIGHT FROM *JOURNAL OF SPORTS REHABILITATION*

Transfer of Copyright: *Journal of Sport Rehabilitation*

Human Kinetics, Inc., P.O. Box 5076, Champaign, IL 61825-5076.

To be completed by the Corresponding Author

Author names (in order of authorship): Robert Bonser, Christy Hancock, Bethany Hansberger, Rick Loutsch, Eric Stanford, Allie Zeigel, Russell Baker, James May, Alan Nasypany, Scott Cheatham

Manuscript Title: Changes in Hamstring Range of Motion Following Neurodynamic Sciatic Sliders: A Critically Appraised Topic

Manuscript Number: ____________________
[To be completed by the editorial office]

Copyright is hereby transferred to Human Kinetics effective if and when the article is accepted for publication in the *Journal of Sport Rehabilitation*; if the manuscript is not accepted, the copyright reverts to the author(s). This transfer of copyright gives Human Kinetics the exclusive right to place the article in various electronic forms in addition to any printed journal. Those forms include, but are not limited to, publication in the journal's "in press" and final online versions on the journal's Web site and in various online databases.

These rights encompass the article in its entirety, including original tables, figures, and any supplementary material that may be part of the final published article. For authors who are employees of the U.S. Government, the transfer of copyright is understood to be effective only to the extent that such copyright is transferable.

The authors explicitly reserve the following rights:

- All proprietary rights other than copyright, such as patent rights.
- The right to use all or part of this article in future works of their own, such as dissertations, lectures, reviews, or textbooks.
- The right to make copies for their own teaching use.
- The right to use original figures and tables in future publications, provided explicit acknowledgment is made of their initial appearance in this journal.
- The right to post an electronic version of the final manuscript, as accepted for publication, on the authors' own Web site or Web site(s) or other electronic repositories controlled by the authors' institution, provided that the electronic version is in PDF or other image-capturing format. The posted version must contain the words "As accepted for publication in *Journal of Sport Rehabilitation*, ©Human Kinetics" and include the DOI link to the article or, if no DOI is available, a URL link to the article's abstract page.

Through signature below, the undersigned author (a) signifies acceptance of the terms and conditions listed above; (b) affirms that written permission has been obtained for all previously published and/or copyrighted material contained in this manuscript and any supplemental materials for print and online publication, as well as any other requisite permissions or releases, and that all such material has been clearly identified in the manuscript; (c) affirms that the manuscript is an original work of authorship that has not has not been previously published, does not infringe any third party's intellectual property rights, and does not contain any material that is defamatory or libelous; and (d) affirms that he/she is authorized to sign this form on behalf of all authors. (In the case of a work made for hire, the below may be signed by the employer.)

Robert Bonser — 4/6/2016

Signature — Date

FOR U.S. GOVERNMENT EMPLOYEES ONLY:
In lieu of the author signature above, author(s) whose work was performed within the scope of their employment with the U.S. Government must provide the signature of an authorized representative, certifying that the work is in the public domain. (If the work was performed under Government contract but the author is not a Government employee, no signature is required in this section.)

I certify that the majority of the authors or the primary authors of the manuscript cited above are employees of the U.S. Government and performed this work as part of their employment and that the paper is therefore not subject to U.S. copyright protection.

Signature and Title — Date

APPENDIX C

PROTOCOL APPROVAL FROM INSTITUTIONAL REVIEW BOARD FROM THE UNIVERSITY OF IDAHO

University *of* Idaho
Office of Research Assurances
Institutional Review Board
875 Perimeter Drive, MS 3010
Moscow ID 83844-3010
Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

To: Russell Baker

From: Sharon Stoll
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

Date: 10/27/2015 3:53:22 PM

Title: Treatment of Apparent Hamstring Tightness Using Total Motion Release® (TMR®) Forward Flexion Trunk Twist (FFTT): A Dissertation in Clinical Practice

Project: 15-966
Approved: October 27, 2015
Renewal: October 26, 2016

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the above-named research project is approved as offering no significant risk to human subjects.

This study may be conducted according to the protocol described in the application without further review by the IRB. Every effort should be made to ensure that the project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

This IRB approval is not to be construed as authorization to recruit participants or conduct research in schools or other institutions, including on Native Reserved lands or within Native Institutions, which have their own policies that require approvals before Human Participants Research Projects can begin. This authorization must be obtained from the appropriate Tribal Government (or equivalent) and/or Institutional Administration. This may include independent review by a tribal or institutional IRB or equivalent. It is the investigator's responsibility to obtain all such necessary approvals and provide copies of these approvals to ORA, in order to allow the IRB to maintain current records.

As Principal Investigator, you are responsible for ensuring compliance with all applicable FERPA regulations, University of Idaho policies, state and federal regulations.

This approval is valid until October 26, 2016.

Should there be significant changes in the protocol for this project, it will be necessary for you to submit an amendment to this protocol for review by the Committee using the Portal. If you have any additional questions about this process, please contact me through the portal's messaging system by clicking the ‘Reply’ button at the top of this message.

Sharon Stoll

University of Idaho Institutional Review Board: IRB00000843, FWA00005639

APPENDIX D

PROTOCOL APPROVAL FROM INSTITUTIONAL REVIEW BOARD FROM TOWSON UNIVERSITY

TOWSON UNIVERSITY

APPROVAL NUMBER: 16-A059

To: Bethany Hansberger
Athletics
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Scot McNary

Date: Tuesday, December 22, 2015

RE: Application for Approval of Research Involving the Use of Human Participants

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Treatment of Apparent hamstring Tightness Using Total Motion release (TMR), Forward Flexion Trunk Twist (FFTT): A Dissertation in Clinical Practice

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: R. Baker
File

TOWSON UNIVERSITY

Date: Tuesday, December 22, 2015

NOTICE OF APPROVAL

TO: Bethany Hansberger **DEPT:** Athletics

PROJECT TITLE: *Treatment of Apparent hamstring Tightness Using Total Motion release (TMR), Forward Flexion Trunk Twist (FFTT): A Dissertation in Clinical Practice*

SPONSORING AGENCY: None

APPROVAL NUMBER: 16-A059

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [ ] is [✓] is not required of each participant

This protocol was first approved on: 22-Dec-2015
This research will be reviewed every year from the date of first approval.

Amy L Taylor for

Scot McNary
Towson University Institutional Review Board