AN EXAMINATION OF THE EFFECTIVENESS OF NOVEL MANUAL THERAPIES TO IMPROVE PATIENT CARE: A DISSERTATION OF CLINICAL PRACTICE IMPROVEMENT

A Dissertation
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with a
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by

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AUTHORIZATION TO SUBMIT DISSERTATION

This dissertation of Alli K. Zeigel, submitted for the degree of Doctor of Athletic Training with a Major in Athletic Training and titled "An Examination of the Effectiveness of Novel Manual Therapies to Improve Patient Care: 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.

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ABSTRACT

The Doctor of Athletic Training degree combines elements of a professional-practice and academic doctorate, with an emphasis on improving clinical practice. The Dissertation of Clinical Practice Improvement (DoCPI) is the culminating project that provides evidence of my evolution and progression as a scholar and advanced practitioner. Included in this document is a case study, which highlights a patient who presented with scapular dyskinesis. In addition to demonstrations of advances in clinical practice, Chapter 3 is an example of scholarship via a study that was completed to establish reliability of a single rater (intra-rater) and multiple raters (inter-rater) when rating V-Sit-and-Reach. The reliability study, found in this chapter, was completed as an effort to expand the available knowledge on the V-SR and to disseminate new knowledge regarding the reliability of the test. Chapter 4 includes two Critically Appraised Topics (CATs), which are manuscripts that have been developed to establish clarity in the literature related to the treatment of patient-reported hamstring tightness. The publications are a part of my professional growth as a scholar who can evaluate our current body of knowledge and disseminate those findings to the athletic training profession. The final component details my primary multisite, *a priori*-designed research, which examined a Total Motion Release (TMR) treatment technique on patients with apparent hamstring tightness. This multi-site research study was designed to assess the effects of TMR (a novel paradigm) in treating hamstring extensibility without targeting the hamstring musculature directly. This fifth chapter serves as more evidence of my progression towards advanced practice and scholarship as an AT.

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DEDICATION

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CHAPTER 1 : NARRATIVE SUMMARY

While pursuing my professional bachelor's degree in athletic training, I became acutely aware of the influence athletic trainers (ATs) have on patient care and on the lives of patients. As I became increasingly integrated in the profession of athletic training, I observed college-aged athletes who sustained injuries but were able to recover with the help of skilled ATs. These clinicians provided patient care from the moment of initial diagnoses through their patients' return to activity. The more I learned about patient care, the more I realized that an AT's potential for influence is much greater than is commonly understood.

Once I began the transition from professional student to practicing professional, I learned that I needed to develop a stronger knowledge-base, specifically in regards to patient care, to gain the trust and compliance of my patients. With the understanding that I needed to further my education and my exposure to advanced patient care strategies, I pursued the Doctor of Athletic Training (DAT) program at the University of Idaho (UI). I chose to attend the DAT program primarily because of the emphasis placed on manual therapies and on advancing one's patient care.

The path for post-professional education in athletic training is not as well-established as other professions. In comparison to other medical professions, athletic training is quite young. In fact, it was only recognized as a medical profession by the American Medical Association (AMA) in 1990 (Delforge & Behnke, 1999). As such, professional and post-professional study has not evolved as much as it has in other healthcare professions. Unlike many other healthcare professions, athletic training only recently announced moving the entry-level education from the bachelor's degree to a master's degree (AT Strategic Alliance, 2015). The profession had also not established a clear path for post-professional training for those who wanted a track focused on improving as clinician as opposed to a researcher. Recently, Seegmiller, Nasypany, Kahanov, Seegmiller, & Baker (2015), suggested the most reasonable subsequent degree for any AT who seeks advanced practice was the DAT degree. The UI DAT program is designed to create advanced practice ATs whose experience and education is focused on improving clinical practice. The UI DAT degree is combines elements of a professional-practice and academic doctorate, with an emphasis on improving clinical practice; students are required to complete a Dissertation of Clinical Practice Improvement

(DoCPI) to provide evidence of their evolution and progression as a scholar and advanced practitioner.

The completion of a dissertation is not uncommon in professional-practice doctoral programs; most professional-practice doctoral education programs [e.g. Doctor of Education (EdD), Doctor of Pharmacy (PharmD), Doctor of Psychology (PsyD)] require students to complete a professional practice dissertation (PPD) (Willis, Inman, & Valenti, 2010). Professional practice dissertations are developed for two primary reasons: 1) to provide evidence of scholarship within the field of practice, and 2) to answer questions that pertain to problems commonly encountered in that practice (Willis, et al., 2010). Working to capture the best of multiple designs, the DAT program requires the DoCPI as a variation on the traditional PPD.

The DoCPI is the culminating product in the DAT program. It illustrates the student's development toward becoming a scholarly practitioner and includes evidence of the student's advancement in clinical practice, research/scholarship, and leadership in the athletic training profession. My DoCPI specifically provides evidence of my clinical practice improvement by highlighting my professional transformation, completed research, dissemination of research, and growth related to patient care.

As a by-product of completing the DoCPI, the student is set on a path towards advanced practice. Nasypany (2013) described an advanced practice AT as "a certified AT who has developed a focused area of clinical practice through the attainment of knowledge and skills both academically and through critical reflection [on] their patient care outcomes." To become an advanced practice AT, a clinician must examine his or her clinical practice, engaging in a perpetual cycle of learning novel patient care strategies, incorporating those strategies into clinical practice, and studying the results. This mindset of continually changing one's patient care as a result of the implementation and study is often referred to as an action research (AR) philosophy with the UI DAT program.

Action research is a key aspect of the pursuit of advanced practice in patient care. It is "a natural way of acting and researching at the same time" (Dick, 2002). This means that every clinician can identify a local problem or issue within his or her patient care, develop a strategy to address the problem, and collect patient outcomes to assess effectiveness, all during daily patient care (Koshy, Koshy, & Waterman, 2011). The cycle then begins again, as the changes

from the study are implemented and the researcher/clinician examines the efficacy of those changes.

Action research improves many aspects of the athletic training profession. Fostering an applied or AR philosophy in one's clinical residency helps to enhance a clinician's proficiency with novel treatments, aids in the discovery of new treatment philosophies, and, most importantly, helps the AT to establish clinical reasoning throughout their patient care. In addition, the patient benefits from the clinician's desire to continually improve upon the treatments he or she performs. Ultimately, the knowledge acquired by the clinician can be disseminated to clinicians who work in the same practice or to other healthcare professionals outside of the clinician's practice. This can result in a widespread change in how patients are treated.

Investigating clinical practice through AR is an important focus of the DAT program, because it creates practicing professionals who are dedicated to consistently working toward increased knowledge, professionalism, and clinical practice improvement. The AR that I have engaged in has helped me learn more about myself as a clinician and about the areas from which my successes and failures have stemmed. Specifically, it has sparked a continued desire to discover answers to the questions that present themselves in clinical interactions; to develop effective, result-oriented interventions for patients; to investigate research questions within my clinical practice and in multi-site settings; and to publish my findings. While not every case I encounter or every research design I create will be publishable, reflecting on my patient care, learning from the past, and expanding my knowledge will always be beneficial to me and my patients.

As an AT performs AR, there are important objective measures that need to be taken to better understand the patient holistically, while also allowing the clinician to study their patient care (Snyder, Valier, Jennings, Parsons, & Vela, 2014). The most common objective measures are patient related outcomes measures (PROMs). Patient related outcomes measures aid in taking a holistic approach to patient care be focusing attention to the patient's overall health (i.e. biological, social, and psychological) and understanding their health-related quality of life (HRQL) (Wilson & Cleary, 1995; Synder, et al., 2014). Utilizing PROMs can aid clinicians in determining alternative or additional causes of injury or pain, instead of focusing solely on the location of pain. To identify other influential components (e.g.,

psychosomatic, daily experiences, traumas), it is important that each PROM has a different focus area that may be local (e.g. foot, ankle, knee, shoulder, etc.) or global (e.g. emotional, psychosocial, etc.) (Snyder Valier et al., 2014). In working to foster a holistic patient care philosophy, I utilize PROMs in a multifactorial fashion, assessing many of the possible factors of a patient's pain.

Since enrolling in the DAT program, my approach toward patient care has become more efficient and effective. Not only have I developed an AR philosophy and a holistic approach to my patient care, I have also developed competence in creating *a priori* research to benefit clinical practice. *A priori* research is a type of AR that is developed by clinicians to study a local problem or frequent injury. The design of the *a priori* study is completed before treating patients who present with the identified local problem. One of the goals of *a priori* research is to better understand injury, as well as the efficacy of a specific treatment or set of treatments for that injury. When using sound methodological approaches and interventions, this research provides evidence of authentic patient care. This evidence can then be disseminated in peer-reviewed presentations and publications that may influence the patient care strategies of other health care providers, as well as provide the impetus for future laboratory-based research.

Although many *a priori* studies are done at a local level, there are also studies that can be completed with other clinicians at multiple clinical sites. Multi-site research allows multiple clinicians across multiple clinical sites to address the same research question (Herriott & Firestone, 1983; Fuller-Rowell, 2000). Clinicians who engage in multi-site research work together to develop research that utilizes the same methodology by each clinician at each site. Although the completion of multi-site research presents its challenges (such as the amount of time it takes to complete such research and the consistency required across researchers in order to obtain valid data), the outcomes outweigh any negative biases. In fact, the multiplicity of location increases the significance of the research results, because the results can be more generalizable across different clinical sites and across multiple clinicians (Kahn, 2012). The curricular design of the UI DAT fosters multi-site research because it allows clinicians with similar interests and goals to work together. The DAT students at the UI have a commitment to research, and they work with one another to address the potential issues of multi-site research. This creates a successful working environment, produces meaningful research that can then be disseminated throughout the athletic training

and other medical professions, and prepares clinical research teams to continue researching relvelant clinical questions throughout their careers.

By completing the DAT program at UI, I have begun my journey to become a scholarly professional who provides excellent patient care and produces meaningful research. I have developed into a scholarly practitioner who can reflectively evaluate her patient care, utilize a holistic approach to patient care, and can conduct and disseminate research. The evidence of this development is found in my DoCPI. Chapter 2 of my DoCPI is a case study that highlights a patient who presented with scapular dyskinesis. A specific and novel intervention, called Reactive Neuromuscular Training (RNT), was directed toward the most dysfunctional component of this patient's scapular dyskinesis to re-establish the functional movement. Through the collection of various outcomes measures, I could track the patient's progress both via special tests and PROMs. This case study is evidence of my progression toward advanced practice and my ability to create patient-care scholarship.

While much of my research has an applied patient-care focus, I have also pursued other important areas of scholarship to continue my development as a researcher. Chapter 3 of this DoCPI, "Intra-rater and Inter-rater Reliability of the V-Sit-and-Reach Test," is a study that was completed to establish reliability of a single rater (intra-rater) and multiple raters (inter-rater) when using this test. A variation of the classic Sit-and-Reach (SR) test, the V-SR requires only a measuring tape and adhesive tape, as opposed to a specially made SR box (Hui, 2000). The reliability study, found in Chapter 3, was completed as an effort to expand the available knowledge on the V-SR and to disseminate new knowledge regarding the reliability of the test.

Chapter 4 includes two Critically Appraised Topics (CATs), which are manuscripts that have been developed to establish clarity in the literature related to the treatment of patient-reported hamstring tightness. The publications are a part of my professional growth as a scholar who can evaluate our current body of knowledge and disseminate those findings to the athletic training profession. The first CAT addresses changes in hamstring range-of-motion when comparing proprioceptive neuromuscular facilitation and static stretching; thus, it is titled, "Changes in Hamstring Range of Motion Following Proprioceptive Neuromuscular Facilitation Stretching Compared with Static Stretching: A Critically Appraised Topic." It was published in the *International Journal of Athletic Therapy and Training* (*IJATT*) journal in

September 2016, Volume 21, Issue 5. The second CAT was completed to assess hamstring range-of-motion changes following sciatic neurodynamic sliders and is titled, "Changes in Hamstring Range of Motion Following Neurodynamic Sciatic Sliders: A Critically Appraised Topic." This CAT was also accepted for publication in the *Journal of Sports Rehabilitation* (*JSR*). Both CATs were developed as work with my multisite research team as part of our effort to provide a clearer understanding to health care practitioners of the current literature pertaining to hamstring range-of-motion and various treatment paradigms relating to that topic. As one my focus areas has been on treating patients with decreased hamstring extensibility, it is imperative to understand that the current research is in gaining hamstring extensibility with the use of static stretching, PNF stretching, and neurodynamic sliders. To increase understanding across the medical fields, we have evaluated and graded the current literature on increasing hamstring extensibility through static stretching, PNF stretching, and neurodynamic sliders.

The final chapter of this DoCPI, Chapter 5, details my primary multisite, *a priori*-designed research, which examined a Total Motion Release (TMR) treatment technique on patients with apparent hamstring tightness. This multi-site research study was designed to assess the effects of TMR (a novel paradigm) in treating hamstring extensibility without targeting the hamstring musculature directly. The results of this study provide justification for clinicians to consider a new mindset for treating apparent hamstring tightness regarding the condition being the result of tight hamstring musculature. This fifth chapter is the final example of how AR can be used to generate solutions to a common musculoskeletal issue (i.e., hamstring tightness), but also serves as evidence of my progression towards advanced practice, and scholarship as an AT.

Throughout my post-professional studies, my vision has been focused on the attainment of advanced practice in athletic training. The DoCPI serves as evidence of my development as a scholarly practitioner and evolution towards advanced practice. My goal was to become an AT who impacted patients' lives and helped them to recover from injury; my patient care has now developed to a level where I feel that I am able to successfully treat any patient and any complaint. Additionally, I have developed a diverse knowledge base, contributed to patient care research, and begun that path towards becoming an advanced practice, scholarly AT. Overall, my DoCPI documents my journey through the DAT program and presents a

detailed summary of my clinical practice improvement, development as a researcher, and advancement as a clinician.

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CHAPTER 2 : ADVANCED PRACTICE MANUSCRIPT

Treatment of Scapular Dyskinesis with Reactive Neuromuscular Training: A Case Study

Background

The scapula is a thin bone that glides along the posterior thoracic wall and contributes to three joints of the shoulder: the scapulothoracic, acromioclavicular (AC), and glenohumeral (GH) joints (Peat, 1986). The scapula has a large surface area with numerous muscle attachments, such as the trapezius, rhomboid, serratus anterior, and rotator cuff muscles (Kibler, 1998). The scapula provides stability to the GH articulation through the contraction of the surrounding muscles to centralize the rotation of the GH joint (Kibler, 1998, Kibler, et al. 2013). Another function of the scapular elevation of the acromion creating sub-acromial space and minimizing the effects of impingement (Kibler, 1998). The position of the scapula adjusts to overhead activity by moving in the following motions: protraction, retraction, elevation, depression, and rotation. When the scapula fails to move synergistically with the GH joint, compensatory and dysfunctional movement patterns are created (Kibler, 1998). Most abnormal movement patterns of the scapula have been suggested to result from poor functioning of the stabilizing muscles of the scapula, which may contribute to GH joint pathologies (Kibler, 1998, Madsen et al., 2011).

Scapular dyskinesis is defined as irregular motion of the scapula (Kibler, 1998; Kibler, et al. 2013). Scapular dyskinesis is often evaluated visually by the clinician from a posterior view with the patient performing active motions (Kibler, 2012; Kibler, 2013; Madsen et al., 2011; Martin & Fish, 2008; Merolla, 2010). One of the results of scapular dyskinesis is increased protraction at the medial border of the scapula during GH motion, such as horizontal adduction, flexion, and abduction (Madsen et al., 2011). The abnormal movement is a result of hyper-activation of the upper trapezius in coordination with decreased activation of the lower trapezius and serratus anterior (Huang et al., 2015). Though nerve damage to the long thoracic and spinal accessory nerves may result in decreased muscular function, the commonality of these pathologies as the cause of the dyskinesis is less than 5% (Kibler, 1998). Other common causes include thoracic kyphosis, clavicular fracture nonunion, high-grade AC joint instability, or soft tissue inflexibility (Kibler, 2012). Treatment of scapular dyskinesis is typically conservative, however, there are cases that do require surgical intervention (Martin

& Fish, 2008). Most conservative rehabilitation includes mobility exercises of the thoracic spine and shoulder (e.g., stretching), closed and open chain strengthening exercises (e.g., push up plus, serratus anterior "ceiling punches"), and other reactive exercises (e.g., catching and throwing). One concern with the treatment of scapular dyskinesis is lengthy treatment protocols; another problem is the treatment protocols are focused on re-education and strengthening surrounding musculature instead of focusing on restoring a functional movement pattern.

As the proposed cause for scapular dyskinesis is the faulty motor recruitment patterns, along with over activation of other musculature, a neuromuscular re-patterning technique such as, Reactive Neuromuscular Training (RNT) may be an effective treatment. The term RNT was first proposed by Voight and Cook (1996) and the primary objective of RNT is to trigger the unconscious process of recruiting the appropriate musculature to establish a proper movement pattern(s) (Voight & Cook, 1996; Guido & Stemm, 2007, Cook et al., 1999). Theoretically, a clinician is utilizing RNT to target the central nervous system (CNS) during rehabilitation exercises to restore appropriate joint movement (Voight & Cook, 1996; Guido & Stemm, 2007). If true, RNT is therapeutically indicated to reflexively re-pattern the neuromuscular system via the CNS to establish appropriate recruitment strategies of involved musculature in particular movements or activities. Currently, few studies have been published on RNT and little is known about its application in patient care. Therefore, the purpose of this case study is to report the outcomes of incorporating RNT into the rehabilitation program of an intercollegiate swimmer diagnosed with scapular dyskinesis who had failed to improve using traditional conservative methods.

Case Report

The patient was a 20-year-old female Division I intercollegiate swimmer who presented with right upper back pain. She described experiencing her current pain for approximately six months without any prior occurrences of this complaint. Her pain was isolated to the right medial border of the scapula, insertion and muscle belly of the right rhomboid, and insertion and muscle belly of the right middle trapezius. She reported gradual onset of her symptoms and did not remember any specific mechanism of injury. When the symptoms initially began, her primary complaint was experiencing pain with breathing, specifically at the end of inhalation. When the pain initially began six months prior, the patient used self-treatment

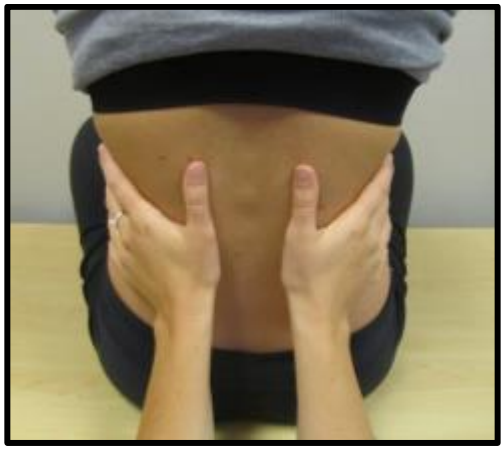
consisting of rest and occasional heat. She reported resting (e.g., no weightlifting or swim training) for three months between academic semesters, but the rest period did not resolve symptoms. When she returned to college for the fall semester, four months after initial onset of pain, the patient reported to the Athletic Training clinic for further evaluation and treatment.

During the initial exam, the patient's chief complaint was pain with inhalation, sitting in good posture, or while wearing a backpack along the medial aspect of the right scapula. The patient did not reveal any red flags for cancer, chronic illnesses, or family history of illnesses. She had experienced pain in the upper right back eight months previously when she was lifting weights, however, the pain resolved without treatment. She was not taking any medication for the discomfort nor had she tried any treatment other than complete rest with all swimming strength and conditioning activities. She reported her worst pain on the Numerical Pain Rating Scale (NPRS) to be a seven out of ten when sitting erect and at the end of an inhalation. A zero on the NPRS is classified as no pain, whereas a ten is classified as the worst pain imaginable (McCaffery et al., 1989). Disability was measured using the Disablement in the Physically Active (DPA) Scale, which is scored from zero (no disability) to 64 (maximum disability) (Vela & Denegar, 2010a; Vela & Denegar 2010b). The day of the examination, the patient reported a disability score of 28 on the DPA Scale. The Patient Specific Functional Scale (PSFS) was utilized to identify activities within her daily life that were causing pain. This scale utilizes a score between zero (cannot perform) to ten (no problem performing) (Stratford et al., 1995). Her three primary activities were breathing (4 out of 10), sitting up straight (4 out of 10) and wearing a backpack (6 out of 10).

The examination did not reveal signs of inflammation, ecchymosis, or deformities surrounding the area of pain. Her natural posture while standing was forward head, forward shoulder, and increased kyphosis. Patient forward head, forward shoulder, and kyphotic posture was considerably increased in the seated position. Assessment of the patient's breathing, while the patient was in a seated position, revealed all of the motion for inhalation was stemming from the chest rather than from the stomach or diaphragm. To test breathing functionality, the clinician used a modification of the Manual Assessment of Respiratory Motion (MARM) test (Courtney, Van Dixhoorn, & Cohen, 2008). The modification of the MARM test was done via palpation and observation to assess the 3-Dimensional movement of the trunk and chest during inhalation and exhalation. The clinician placed their hands along

the patient's mid to low back with the thumbs parallel to the spine and fingers splaying laterally (Figure 2.1). While the patient completed normal inspiration/expiration, the clinician felt for the motion of breathing to either be lateral, superior, anterior, and/or posterior. A normal pattern consists of lateral, anterior, posterior, and limited superior motion (Chaitow, 2014) and the modified MARM for this patient revealed a primary upward motion in breathing, with absent posterior and lateral motions with inhalation.

Figure 2.1: Hand positioning for modified MARM test

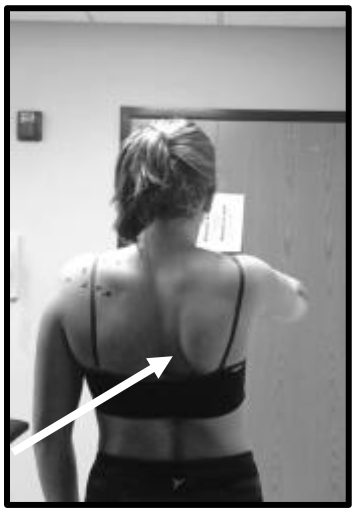


Tender points (TPs) at the middle portion of the insertion of the rhomboid minor, superior portion of the insertion of the rhomboid major, middle trapezius superior portion of the insertion and superolateral muscle belly, and serratus posterior superolateral muscle belly were identified with palpation. In addition to reporting TPs, the patient stated that she generally felt "tighter" on the right side, medial to the scapula, compared to the left side. As a component of the clinicians breathing assessment, the patient also reported tenderness to palpation at the first, second, eleventh, and twelfth ribs in a supine position.

Range of motion testing was performed and revealed no limitations or pain with any of the following active range of motions (AROM) at the shoulder: flexion, extension, internal rotation (IR) at a 90-90 position, external rotation (ER) at a 90-90 position, abduction, horizontal adduction, or horizontal abduction. Observation during AROM testing revealed the patient had substantial scapular dyskinesis on the right side that was most prominent with flexion, abduction, and horizontal adduction (Figure 2.2). The following passive ranges of motion (PROM) at the shoulder were equal bilaterally, within normal limits, and non-painful: flexion, extension, IR, ER, horizontal adduction, and horizontal abduction. Strength testing of

the rotator cuff muscles, deltoid, pectoralis major, biceps brachii, and triceps brachii were all 5/5 and non-painful when compared bilaterally. The right rhomboid had decreased strength, 4/5, when compared bilaterally.

Figure 2.2: Scapular dyskinesis pre-treatment (Located at the end of the arrow)



The patient also displayed a positive sulcus sign bilaterally and scapular dyskinesis on the right when in a push up plus position both in non-weight bearing and weight bearing. Based on the lateral scapula slide test (LSST), the patient met the established threshold, 1.5cm, of difference during 90 degrees of abduction and was .2cm and .3cm from the threshold in the positions with hands on hips and at 90 degrees horizontal adduction (Table 2.1) (Kibler, 1998; Curtis & Roush, 2006; Ozunlu, et al., 2011). The scapula slide test was performed with the patient standing. Each measurement was taken from the spinous process even with the inferior angle of the scapula for each motion. The LSST was performed first with the patient's hands by her side, then progressed to hands on the hips, and 90 degrees of abduction with the patient in full internal rotation. Though the LSST is designed exclusively for those three motions, the clinician also measured the differences when the patient completed horizontal adduction. The Apprehension and Relocation, Empty Can, and Gerber Lift Off tests were negative. All neurological screening and function was within normal limits. Based upon these findings, the patient was classified with right scapular dyskinesis and conservative rehabilitation was initiated.

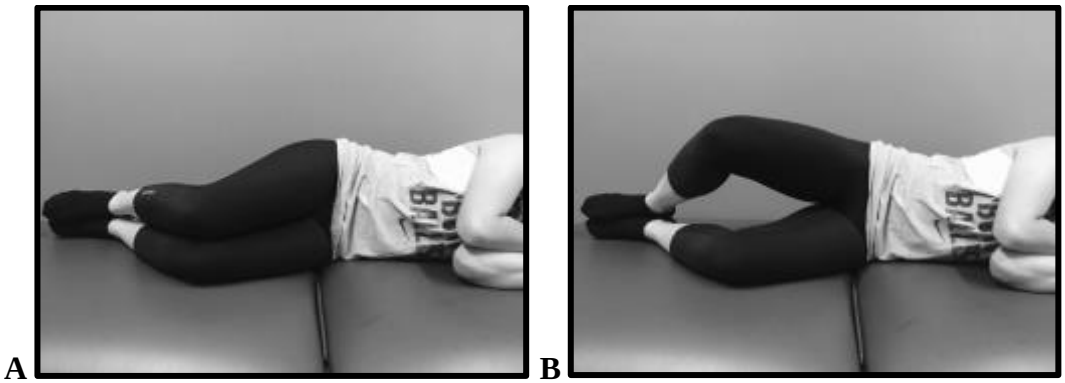
Table 2.1: Measurements taken in the scapular slide test. Numbers reported in centimeters.

	Left	Right	Left	Right
Arm Position	Day 1		Day 3	
Down by sides	9.5	9.5	9.5	9.5
Hands on hips	8.9	10.2	8.9	8.9
90 degrees abduction	10.2	7.6	10.2	10.2
90 degrees horizontal adduction	12.7	14	12.7	12.7

Intervention

The first six weeks of treatment and rehabilitation consisted of a combination of moist heat packs (MHP), Positional Release Therapy (PRT), breathing retraining, Primal Reflex Release Techniques (PRRT), instrument assisted soft tissue mobilization (IASTM), massage, strengthening, and stretching. Treatment sessions began with MHPs to stimulate blood flow to the affected area, and to help increase patient relaxation and comfort. After the application of the MHPs, PRT was used to release the TPs present during the initial evaluation. Following PRT, breathing retraining exercises were used to restore normal diaphragmatic breathing; the techniques utilized were a combination of breathing exercise developed by Michael Grant White (White, 1997) and PPRT techniques developed by John Iams (Nasypany, 2016). The breathing exercise was similar to the traditional "clam shell" exercise for hip external rotator strengthening (Figure 2.3). However, the breathing component required the patient to attempt maximal exhalation (i.e., "blow all your air out") and then move through full hip external rotation with the top leg and hold their breath throughout the motion. Once the knees returned to the starting position, the patient was cued to inhale. The length of the count varied by the patient's ability to hold her breath. When the patient returned to the starting position, the required response was to have the patient take a "gasping" breath, meaning the patient felt as if she could not hold her breath any longer, thus taking a large reflexive inhalation.

Figure 2.3: Starting (A) and ending position (B) of the "clam shell" exercise



The PPRT technique was then used to address the patient reported rhomboid tightness. Initially, a facilitation technique was used on the rhomboids due to the posture of the patient (i.e., forward shoulder); however, the technique did not produce improvement, so the clinician then inhibited the rhomboids in an attempt to decrease pain and tightness. Next, IASTM and massage were used to reduce remaining TPs on the affected side rhomboid major, rhomboid minor, upper and middle trapezius, and serratus posterior, as well as to restore function and ROM. Exercises were used to increase muscular control and strength of the serratus anterior and lower trapezius muscles to improve scapular stabilization within a functional movement pattern. (Table 2.2). Finally, a stretching regimen was used to lengthen tight anterior musculature and improve posture.

Over the first six weeks of therapy, the patient would complete this therapy protocol 1 time per day and four days per week, on average. During this time period, the patient reported short-term pain relief and TP reduction. The patient typically reported a decrease in pain following each treatment session; however, the pain and TPs returned without any noticeable improvement by the end of a two-hour practice or her next visit. When a treatment was provided prior to practice, the patient reported a resolution of her complaint, but it would only remain resolved through 50 to 75% of the practice period (~2 hours). Treatment provided on non-training days followed a similar pattern, but usually increased the duration of her pain resolution from approximately 90 minutes to 3 hours on average. During these six weeks, discernable improvements in the patient's strength and dyskinesis were recorded (Table 2.3). Due to the lack of patient-reported or disease-oriented improvement, the clinician re-evaluated the patient and decided to add RNT to her established rehabilitation protocol. The clinical reasoning for this choice focused on the belief that patient functional motor patterns (i.e.,

stability) were not being established at the unconscious level and a more reactive training program was needed to normalize movement patterns and postures at the unconscious level.

Table 2.2: Frequency and duration of each rehabilitative exercise performed.

Exercise:	Times per Week*	Weeks Exercise was Performed	Duration
Low row/ scapula pinches with a red thera-band	2-3	2	3x8-10
Supine Scapular Retraction	1-5	2	2x8
Standing Scapular Retraction Against Physio Ball	1-5	3	2x10
Scapular control exercises with the patient holding a weighted ball and moving into flexion, horizontal adduction, horizontal abduction, and abduction	2-3	4	3x30 seconds
Push up plus on BOSU	2	3.5	3x8
I's, Y's, T's	2	3.5	2x8
Horizontal adduction with 3lb weighted ball with RNT	2	1.5	3x10

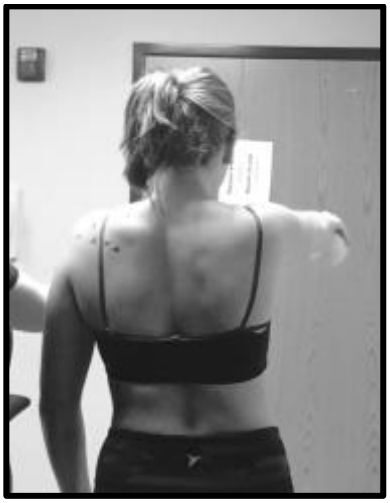
*Times per week varied weekly based on availability and travel.

The initial treatment goal for utilizing RNT was to decrease scapular dyskinesis during standing horizontal adduction because this was the most difficult movement for the patient and location of the worst scapular dyskinesis. The patient continued to use MHP prior to beginning exercises because she felt that the MHP helped to decrease pain and increase her mobility. The treatment protocol was MHP, RNT with horizontal adduction, I's, Y's, T's on two of the days, BOSU push up plus on one day, while the patient also continued to stretch the pectoralis muscles as she had been doing daily. The clinician first applied stimulation for RNT to various places on the anterior aspect of the patient's body (e.g., upper 1/3 of the sternum, middle of the sternum, xipoid process, upper abdomen, lower abdomen, and bilateral ASIS) to determine the best location based on the response from the patient. The response the clinician was testing for was the largest decrease in the scapular dyskinesis during one repetition of horizontal adduction with the external stimulation. While the clinician applied the anterior to posterior force via hand pressure, the patient was instructed to not allow the clinician to push her backwards. Further, the patient was instructed to perform horizontal abduction as soon as the

clinician applied the pressure. When the stimulation was applied to the middle of the sternum, the scapular dyskinesis ceased while the patient performed horizontal adduction (Figure 2.4).

On the first day of treatment with RNT, the patient performed two sets of ten repetitions with the pressure in the middle of her sternum. A third set was completed with the patient closing her eyes and imagining the pressure on her chest before completing the movement. When the patient imagined the pressure, the elimination of dyskinesis was consistent with the clinician applied force. Days two and three of RNT consisted of the same treatment, but on these days, the patient performed one set of ten repetitions with clinician generated force, while the second and third sets were done with the imagination of the pressure. The NPRS was collected pre and post each treatment, PSFS was collected pretreatment, and the DPA Scale was collected at day one, at discharge (day three), and eleven-months post-discharge. The patient denied taking any medications for pain and maintained her activity level throughout the course of the new treatment protocol. The patient was treated two consecutive days, then 6 days later for the third treatment. The patient did not return to the clinic until 6 days following the third treatment, reported resolution of symptoms and no treatment was performed as discharge criteria was met. Discharge criteria had been previously established as the ability to maintain normal scapular stabilization throughout function movements (without RNT), an average NPRS score one out of ten or below, and a PSFS of a nine out of ten or higher with intercollegiate swimming and conditioning activity.

Figure 2.4: Scapular dyskinesis was eliminated when pressure was applied to the middle of the sternum



Results

Prior to using RNT as a treatment, the patient had received 26 days of treatment over six weeks without any lasting improvements (Table 2.3). Reactive Neuromuscular Training was then used during three treatments over a seven-day period with lasting resolution of symptoms (Table 2.4). The final evaluation occurred six days after the third RNT treatment and the patient met all of the established discharge criteria. At this time, a full re-evaluation was performed, intake data was collected, no treatment was performed, and the patient was cleared to continue unrestricted physical activity. The physical exam at this visit revealed the scapular slide test was equal bilaterally; however, the patient's primary chest breathing pattern remained in a seated position, but diaphragm activation was present. The TPs on the insertion of the rhomboid major and insertion and muscle belly of the middle trapezius were no longer present during palpation. The TP at the middle portion of the rhomboid major was still present, but the patient reported the tenderness was mild (2/10) compared to prior to treatment (4/10). The patient's natural sitting posture was still forward head, forward shoulder, and increased kyphosis; however, these postures were not as extreme and the patient reported that it was easier to maintain better posture and without pain. The patient was released to full activity (i.e., swimming, dryland training, and weight lifting) and was monitored throughout the remainder of the swim season; follow-up measurements were conducted at 2 weeks and 11 months post-discharge (Table 2.4).

Detailed evaluation of patient outcomes utilizing RNT treatment revealed the patient demonstrated a change in pain that met the minimal clinically important difference (MCID) on the NPRS after Day 1, but it took 3 visits for this change to be maintained between treatment sessions and a few weeks post-discharge until current pain was fully resolved (Table 2.4) (Hefford, et al., 2012). Functional improvement followed a similar pattern based on PSFS scores; the patient did not report maintenance of functional improvement until after the third treatment and her functional impairment remained resolved at 11 months post-discharge. Additionally, the patient's scapular winging improved. At the initial exam, the patient displayed a 1.3 cm difference side to side of scapular winging with horizontal adduction; however, at discharge, the patient had an even distance scapula to spinous process with horizontal adduction. As with the other measures, this improvement was maintained at the 11-month follow-up visit.

Table 2.3 Patient Outcomes Prior to RNT with Horizontal Adduction.

	Treatment Day 1	Treatment Day 11	Treatment Day 21
NPRS - Current	8	7	4
NPRS - Best	5	7	4
NPRS - Worst	8	7	5
NPRS - Average	7	7	4.33
NPRS –Post	6	6	3
DPA Scale	28	15*	N/A
PSFS	7.75	7	7.6

Abbreviations: DPA Scale- Disability of the Physically Active Scale, PSFS- Patient Specific Functional Scale (0=unable to perform, 10= fully able to perform), NPRS- Numeric Pain Rating Scale at current, best within past 24 hours, worst within last 24 hours, average of current, best and worst (0=no pain, 10=worst pain). Pre-Tx: Pre-treatment. Post-Tx. Post-treatment. N/A: Not applicable.
Legend: * - Met MCID criteria

Table 2.4: Patient Outcomes with RNS Treatment During Horizontal Adduction.

	RNT Tx 1	RNT Tx 2	RNT Tx 3	6 day F/U	2 wk F/U	11 mon F/U
DPA Scale	22	N/A	16	N/A	N/A	4
PSFS	8	N/A	7	9.5*	N/A	10
NPRS-Current Pre-Tx	4	4	4	1	2	0
NPRS-Current Post Tx	2	3	2	N/A	N/A	N/A
NPRS-Change	2*	1*	2*	N/A	N/A	N/A

Abbreviations: DPA Scale- Disability of the Physically Active Scale, PSFS- Patient Specific Functional Scale (0=unable to perform, 10= fully able to perform), NPRS- Numeric Pain Rating Scale at current, best within past 24 hours, worst within last 24 hours, average of current, best and worst (0=no pain, 10=worst pain). Pre-Tx: Pre-treatment. Post-Tx. Post-treatment. N/A: Not applicable.
Legend: * - Met MCID criteria

Discussion

Worsley et al. (2013) used a general rehabilitation program to retrain scapular stabilizers over a course of ten weeks to treat shoulder impingement. The researchers found the serratus anterior and lower trapezius could successfully be retrained over ten weeks and scapular motion was nearly equal to a healthy population, after the protocol was completed (Worsley et al., 2013). The long-term benefits of this program are unknown; however,

rehabilitation for scapular dyskinesis commonly targets the decreased activation of the serratus anterior and middle trapezius (Huang et al., 1995).

In this case study, the initial focus was on relieving pain through soft tissue treatments and increased strength of the para-scapular musculature; however, the intervention shifted towards restoring optimal movement patterns of the scapula. Unlike exercise-based therapy, RNT may be beneficial from an evaluative and treatment standpoint because of the immediate restoration of a functional movement pattern when the clinician applies the external force (Loutsch, et al., 2015). If the functional movement pattern is not restored, either the wrong force is being applied (e.g., not enough force, wrong location) or RNT is not indicated (Cook, 2010). The location or amount of force may vary from patient to patient; however, when indicated, the treatment should produce an instantaneous, noticeable, and long-lasting improvement in movement (Loutsch, et al., 2015).

The proposed theories behind the success of RNT are centered around the influencing the CNS. Reactive Neuromuscular Training targets every level of the CNS to create a motion that stabilizes a joint or initiates the contraction of necessary muscles (Voight & Cook, 1996; Guido & Stemm, 2007; Borsa, et al., 1994). As the CNS reacts to a stimulus to create joint stability, there is a conversion from conscious thought to unconscious (Voight & Cook, 1996). The treatment was applied to the sternum with a varying amount of force and frequency, requiring the patient to react opposed to anticipating and forces the reaction to become unconscious. Borsa et al. also explains that the more a motion or stimulus is repeated, the brain will store these movements or stimuli and have the ability to access the response unconsciously (1994).

Currently, there are no published studies or case reports on utilizing RNT for scapular dyskinesis; however, there are published reports on the use of RNT in other areas. The ability to complete a previously poor motor pattern, functionally without conscious thought was elicited in a case study using RNT for apparent hamstring tightness (Loutsch, et al., 2015). The patient in this case was tested on a variety of hamstring extensibility measurements and was classified with hamstring tissue extensibility dysfunction (TED). After one treatment of RNT during multi-segmental flexion, reported gains in ROM for nearly all ROM measurements immediately following the intervention and the improvements were maintained at the five-week follow-up without further intervention that exceeded all gains in the stretching literature

(Loutsch et al., 2015). Not only were the gains in all ROM testing improved, but the gains in motion were enough to be within the normative ranges for each ROM measurement tested (Loutsch, et al., 2015). Additionally, RNT has also been reported to be beneficial in a case report on Anterior Cruciate Ligament (ACL) deficiency (Cook et al., 1999). Over the course of eight visits, a patient experienced a large increase in strength that could only be explained by neuromuscular adaptations opposed to true strength increases (Cook, Burton, & Fields, 1999). Traditional strength gains require several weeks to occur, whereas neuromuscular adaptations within the body occur during the first six weeks of training (Cook, Burton, & Fields, 1999). Thus, over the course of eight treatments the gains made must have been a result of neuromuscular adaptations (Cook, Burton, & Fields, 1999). While these two cases suggest RNT may be an effective intervention, reports on the effectiveness of RNT could not be identified in the literature.

In the current case, applying RNT required a contraction of anterior chain muscles, in particular the abdominal muscles, before trying to move the arm. The contraction and subsequent stabilization correct faulty stabilization patterns allow for more ideal functional movements, in this case, shoulder horizontal adduction. The serratus anterior and lower trapezius are typically the muscles that are not activating appropriately (Huang et al., 2015), thus activating the core for this patient may have created the proper stability for the serratus anterior and lower trapezius to activate and stabilize the scapula properly. Throughout the three days of treatment with RNT, the patient's pain continually decreased immediately after treatment; however, the following day the pain had returned to the same level as the day before. After the third treatment, the patient experienced clinically significant improvement the improvements were maintained.

Due to the limited research on RNT, we do not know what the ideal number of treatments, sets, or repetitions required for the best treatment results when using RNT. In addition, we also do not know if there is any variance across areas of the body, with different motions (e.g., are complex movement patterns more difficult to restore), or with different pathology. There could be differences in treatment time, frequency, and duration depending on the structures involved or the severity of injury to produce meaningful change. For example, multi-segmental flexion, a uniplanar motion, required only one treatment to produce significant results (Loutsch, et al., 2015). In contrast, the patient with a deficient ACL completed eight

days of treatment with RNT and may have needed more if time permitted in that case. In this case, the patient did not only have one dysfunctional motion, but instead need to restore functional movement through multiple complex movement patterns. Though the motions that needed restoration were complex, they only required three treatments for a case of scapular dyskinesis to meet discharge criteria and maintain these improvements at 11-month follow-up.

The presented case provides preliminary evidence that RNT may be an effective treatment option, at least as adjunct therapy, for patients with scapula dyskinesis. Future research needs to be completed on RNT in the treatment of scapular dyskinesis to determine the effectiveness of the treatment across a larger population size to determine its effectiveness as an adjunct and individual treatment. Additionally, future research should be performed to determine the appropriate dosage of RNT to restore and maintain functional movement patterns.

Conclusion

The results of this case study provide an example for the potential benefit of utilizing RNT; the reactive component of the case study presents clinical reasoning that may help clinicians identify when to use RNT and use it earlier in a therapeutic rehabilitative program. Also, this case supports the importance of collecting and reflecting on patient outcomes; evaluating patient outcomes helps determine treatment efficacy and illuminates whether to continue or discontinue the treatment plan. In this case, after adjusting the treatment protocol to include RNT as the primary intervention, the patient reported clinically significant improvement in pain and function. The patient was pain free after three days of treatment and remained fully functional and with reduced pain 2 weeks and 11-months post conclusion of the treatment after a multi-modal conservative rehabilitation program had failed to produce meaningful improvement over 6 weeks. Based on these results, further research on the use of RNT with scapular dyskinesis is warranted to determine effectiveness, but this case may serve as a clinical guide for incorporating RNT into patient care.

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CHAPTER 3 : CLINICAL OUTCOMES MANUSCRIPT

Intra-Rater and Inter-Rater Reliability of the V-Sit-and-Reach

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Abstract (100-300 words):

We investigated the intra-rater reliability and inter-rater reliability for the V-Sit-and-Reach (V-SR) test. The study sample consisted of 24 healthy participants; 14 females (30.2 ± 4.0 years, 25.9 ± 2.7 BMI) and 10 males (33.5 ± 6.6 years, 27.0 ± 2.8 BMI). Each participant was rated by the 6 raters at two time-points, one week apart. The V-SR was performed with the patient in a long sit position on the floor and flexed at the hips and reaching for their toes three times. On the third attempt, the rater recorded the number by the nearest centimeter. Statistically significant ICC values were observed for both inter-rater and intra-rater reliability. Inter-rater reliability ranged from 0.97 to 0.99 and intra-rater reliability ranged from 0.95 and 0.97, classifying the both values as "excellent reliability". Additionally, Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC) values were calculated and established to have an average of 2cm and 5.8cm respectively. These results provide evidence that the V-SR is a reliable test both within and between novice raters, while also providing the expected amount of error and minimal changed needed to be meaningful in changes of flexibility.

Keywords (3-5):

Sit-and-reach, Hamstring, Lumbar, Flexibility, Range of Motion

Introduction

Muscular flexibility is defined as the muscle's ability to lengthen, allowing one or more joints to move through various ranges of motion (ROM) (Zachezewski, 1998). Flexibility is affected by a number of factors, such as distensibility of the joint, ligamentous compliance, and muscle viscosity (ACSM, 2000). Flexibility imbalances have been indicated to lead to deficiencies in functional performance, resulting in pain, injury and altered movement patterns (Cook, Burton, & Hoogenboom, 2006). Routine flexibility exercises are frequently recommended to maintain healthy muscle flexibility and joint ROM (Garber et al., 2011). Range of motion tests are regularly utilized in many settings to assess flexibility and joint motion in orthopedic evaluations and health related fitness testing (American College of Sports Medicine, 2014; Baltaci, Un, Tunay, & Gerçeker, 2003; Beets & Pitetti, 2005; Cuberek, Machová, Lipenská, 2013; Mayorga-Vega, Merino-Marban, & Viciana, 2014). The flexibility of the hamstring muscle group is one of the, if not the most, commonly assessed muscle groups in these settings because of high correlations with decreased flexibility and low back pain and increased risk of injury (Harreby, et al., 1999; Shadmehr, Hadian, Naiemi, & Jalaie, 2009; Junker & Stoggl, 2015; Mason, et al., 2016). When isolating the hamstring muscle group alone, the passive straight leg raise (PSLR) is considered the gold standard (Gadjosik, 1985); however, in many settings, the sit-and-reach (SR) test more often is used to evaluate lumbar and hamstring flexibility (ACSM, 2014; Mier & Shapiro, 2013; Mayorga-Vega, et al., 2014; Cuberek, et al., 2013).

The classic SR test is performed with the participant in a long-sit position (sitting with legs straight out in front) and the feet flat against the SR box. The participant then slowly flexes at the hips and reaches toward the toes as far as possible with extended arms (Baltaci, et al., 2003; Mier & Shapiro, 2013; Muyor, Vaquero-Cristobal, Alacid, & Lopez-Minarro, 2014;). The distance the participant reached is then recorded (Baltaci, et al., 2003; Mier & Shapiro, 2013; Muyor et al., 2014). The classic SR test has been found to have moderate (r=.38; Castro-Piñero, Chillón, Ortega, Montesinos, Sjöström, & Ruiz, 2009) to good validity (r= .79; Ayala, Sainz de Baranda, De Ste Croix, & Satonja, 2012b). In a recent meta-analysis, a cumulative moderate correlation (r = .67) was found when comparing the classic SR test to the PSLR or active knee extension test (Mayorga-Vega, et al., 2014). The reported cumulative validity of the classic SR for lumbar spine flexibility was not as good (r = .27); however, the test was compared to a

variety of tests (i.e., Macrae & Wright test, single inclinometer method, American Academy of Orthopedic method, or spinal Mouse method) and the methodologies varied widely within the studies (Mayorga-Vega, et al., 2014). The classic SR has also been found to have high intra-rater reliability (ICC = .91 - .96; Jackson & Baker, 1986; Jones, Rickli, Max, & Noffal, 1998). Though the classic SR test is commonly used, a number of modified versions of the classic SR test, such as the back-saver SR, modified SR, unilateral SR, chair SR, and V-SR have been developed.

These alterations have been developed for various reasons including: accounting for leg length differences, decreasing pressure on intervertebral discs, increasing ease and accessibility of use, and to test specific locations in the body (i.e. lumbar spine, thoracic spine) (Ayala, Sainz de Baranda, de Ste Croix, & Satonja, 2012a; Baltaci, et al., 2002; Cuberek, et al., 2013; Hui, Yuen, Morrow, & Jackson, 1999; López Miñarro, Andújar, García, & Toro, 2007; Mayorga-Vega, et al, 2014; Patterson, Wiksten, Ray, Flanders, & Sanphy, 1996). In particular, the V-SR test is a simplified version of the classic SR test that continues to measure hamstring and lumbar flexibility. The V-SR test is named based on the positioning of the participant, who is asked to sit on the floor with the feet separated 30-cm apart, making a "V" with their legs (Hui, et al., 1999; Hui & Yuen, 2000). A benefit of the V-SR in comparison to the classic SR is the elimination of costly materials, as the only equipment required includes a measuring tape and adhesive tape (Cuberek, et al., 2013; Hui & Yuen, 2000).

In comparison to the classic SR, the V-SR has low to moderate validity for assessing both hamstring flexibility compared to the PSLR (r = .58 to .63) and lumbar spine flexibility compared to the Macrae & Wright test (r = .42; Hui & Yuen, 2000). The V-SR test has been found to have high intra-rater reliability (r = .98) among participants who performed self-administration of the test (Cuberek, et al., 2013). Though the test is more commonly performed with an external rater (e.g., physical educator, clinician), evidence for the inter-rater and intra-rater reliability for the V-SR using these methods could not be identified in the literature (Cuberek et al., 2013). Thus, there is a gap in the literature regarding the inter- and intra-rater reliability of a clinician administered V-SR. No previous V-SR reliability studies identified in the literature indicate the standard error of measurement (SEM) or minimal detectable change (MDC) for the test. Additionally, there is no other study we identified that has used an ICC value to establish both intra-rater and inter-rater reliability. Therefore, the purpose of this study

was to determine intra-rater and inter-rater reliability, and SEM and MCD values, of the V-SR test for novice raters.

Methods

Participants

Twenty-four healthy adults from the XXXXX volunteered to participate in the study from a convenience sample. The participants consisted of 14 females (30.2 ± 4.0 years, 25.9 ± 2.7 BMI) and 10 males (33.5 ± 6.6 years, 27.0 ± 2.8 BMI). Inclusion criteria for this reliability study were healthy participants between the ages of 18 and 50 years old. Exclusion criteria for this reliability study were 1) unable to hold long sit for more than 5 seconds; 2) experience pain while performing the test; 3) known lumbar spine pathology limiting ROM (discogenic); 4) vestibulocochlear disturbances/concussion; 5) joint hypermobility syndrome (Beighton Score of four or higher); or 7) became injured between the first and second day of the study. Before completing the V-SR, the participants received an explanation of the purpose and procedures. The participants were given the opportunity discontinue testing at any point throughout the duration of the study. No adverse reactions were reported and no participants withdrew from the study. The study was approved by the XXXXX's Institutional Review Board (IRB) (IRB #).

Data Collection

A total of six raters were used. The raters were all certified Athletic Trainers (ATC) and had a range of one to twelve years (M = 6.17 ± 3.97 years) of clinical experience. Though all of the raters were experienced clinicians, they were novices in performing the V-SR test. A review of the literature was conducted and testing procedures were established. The procedure was provided to, and reviewed by, each rater, but no other formal training for performing the V-SR was completed prior to beginning data collection.

The V-SR was set up in stations prior to participants reporting for testing. There were six stations spread out throughout a basketball gymnasium. At each station, two boxes were placed against a wall and a retractable Medco® Sports Medicine cloth tape measure (150cm) was affixed to the floor using pieces of Duck® Tape Beige General Purpose Masking Tape (18mm X 55m). Though many previous studies that used the V-SR did not have any blocks for the participants' feet, we used boxes like a study done by Lopez-Miñaro, et al. (2008) to limit inconsistencies in ankle positioning which could influence apparent hamstring flexibility

(Gadjosik, LeVeau, & Bohannon, 1985) or impact testing consistency. A piece of tape denoting the baseline "zero" point was placed at the 40cm mark of the cloth tape measure. On the baseline tape strip, two marks were placed 15cm on either side of the tape measure to denote the spot where the participant's feet would be placed (Figure 3.1).

Each participant was randomly assigned a number, then partnered with one other participant. The pairs were then assigned to one of the six stations for testing. No warm up or stretching was performed prior to the V-SR testing. Testing was conducted by instructing the participants to sit on the floor with the legs extended, the feet spaced 30cm apart, and the plantar surface of the feet touching the boxes to keep the ankle joints in a neutral position (Figure 3.2; Gadjosik et al., 1985). An assistant placed one hand superior to patella on one leg to ensure the patient would maintain the extended position, while the tester ensured the participant maintained position on the other leg. The participant placed one hand over top of the other and flexed at the hips towards the toes to the point of discomfort (Figure 3.3). The motion was performed three times and the measurement was recorded on the third attempt. The tester measured from the edge of the baseline "zero" tape line to the tip of the middle finger. A measurement of "zero" indicated the fingertip was in line with the edge of the baseline "zero" tape line. A negative number indicated the fingers had not reached the baseline "zero" edge of the line, while a positive number indicated the fingers went past the baseline "zero" edge of the line. Measurements were rounded to the nearest half centimeter for recording. Once the tester had rated each participant, the pair of participants moved on to the next testing station. The testing procedure was repeated in this rotation formation until each tester had rated each participant. All participants returned to the gymnasium one week later at approximately the same time in the afternoon to complete the V-SR again using the same methods and cues. During the seven days between measurements, the raters were blinded to the results from the first day. After testing was completed, the results from the two testing periods were combined for analysis.

Statistical Analysis

All data analysis was performed using IBM® SPSS® Version 23 for Macintosh. An interclass correlation coefficient (ICC 3,1) was used to determine inter-rater reliability and intra-rater reliability (Weir, 2000; Vincent & Weir, 2012). The ICC values were identified using a single measures two-way mixed model with absolute agreement and 95% CI. The

ICC for intra-rater reliability was calculated using the measurement from the initial day of V-SR testing and the measurement from the assessment one week following for each rater. The ICC value for inter-rater reliability was calculated using the data that was collected on the one week follow-up of V-SR measurements for each rater. Reliability cut-off values were established a priori; 0.4 > ICC <0.75 indicated fair to good reliability and ICC $\geq$ 0.75 indicated excellent reliability (Zaki, Bulgiba, Nordin & Azina Ismail, 2013).

Calculations were also completed to determine the standard error of measurement (SEM) and minimal detectable change (MDC) values. The SEM is used to indicate the error range that can be expected upon measuring the V-SR (Hurley, et al., 2011). The SEM was calculated with the following equation (Weir, 2000): $SEM = SD\sqrt{1 - ICC}$ (SD= standard deviation, ICC= interclass correlation coefficient). The MDC values were also established for individual raters (Table 3.1) The MDC is a value that illustrates the amount of change on a test required to be confident the change was truly an improvement and not error (Vincent & Weir, 2012). The MDC values were calculated by the following equation (Weir, 2000): $MDC = SEM\ x\ 1.96\ x\ 2$.

Results

In this study, the raters had excellent inter-rater and intra-rater reliability (Table 3.1 & 3.2). The ICC value for inter-rater reliability ranged from 0.97 to 0.99 (Table 3.2) with an average of 0.98. The ICC values for intra-rater reliability ranged between 0.95 and 0.968 (Table 3.1). All values for inter-rater and intra-rater are classified with having excellent reliability (Zaki et al., 2013). Standard error of measure values were calculated through IBM® SPSS® for each rater individually (Table 3.1).

Table 3.1: V-SR Intra-rater Interclass Correlation Coefficient (V-SR ICC), Standard error of measurement (SEM), Minimal detectable change (MDC), and 95% Confidence intervals (95% CI).

Rater	V-SR ICC	SEM	MDC	95% CI
1	.95	2.12	5.94	.887- .978
2	.956	2.12	5.93	.901- .981
3	.958	2.14	5.98	.906- .982
4	.945	2.05	5.74	.878- .976
5	.956	2.05	5.73	.900- .981
6	.968	1.99	5.50	.926- .986
Range	.95-.968	1.99- 2.14	5.50- 5.98	.878- .986
Average	.955	2.08	5.8	----

Table 3.2: Inter-rater interclass correlation coefficient (ICC) values.

	#1	#2	#3	#4	#5	#6
#1		0.973	0.991	0.983	0.978	0.985
#2			0.968	0.992	0.984	0.978
#3				0.976	0.978	0.988
#4					0.991	0.988
#5						0.99
#6						

Inter Rater Range: .968- .99 (.983- average)

Discussion

Novice raters can demonstrate excellent intra-rater and inter-rater reliability on the V-SR.The raters who performed the V-SR in this study had a varying years of experience, ranging from 1-12 years (M = 6.17 ± 3.97 years), but had no previous experience using the V-SR. Despite the novelty of the test, the raters demonstrated excellent reliability (Table 3.1 and 3.2). These findings suggest the V-SR may be easily administered by novice clinicians who follow standardized testing procedures and supports previous reliability findings for the V-SR (Zaki et al., 2013).

The SEM and MDC values calculated in this study are the first values we could identify in the literature for the V-SR. We found that the average expected error while performing the

V-SR is approximately 2cm whereas the MDC average value is 5.8cm. This value provides baseline evidence for health care professionals and physical educators to identify when true, meaningful changes in motion or flexibility occur on the V-SR. Clinicians, physical educators, and others may use these results to understand not only the reliability of the VSR, but also the error that may occur between measurements, which helps guide conclusions on improvements for the patients, clients, or students following an intervention.

Despite the paucity of research on the V-SR, our results also provide additional clarity when compared to the available literature examining the reliability of the test. Cuberek et al. (2013) previously studied the intra-rater reliability for self-administration of the V-SR test and used the Person r statistical assessment to determine the intra-rater reliability. This is problematic because the Pearson r statistic is not sensitive to changes over time (Arnold, Gansneder, & Perrin, 2005). Additionally, the Pearson r is not sensitive to errors within a clinician's rating or that one to two clinicians do not have more errors than another one or two clinicians (Arnold, et al., 2005). Thus, our study is beneficial to the current body of literature because of the use of an ICC statistic to determine both inter-rater and intra-rater reliability. The ICC statistic was used in our study because it better assesses the data by treating the systematic variability as an error (Holmbäck, Porter, Downham, & Lexell, 1999; Henriksen, Moe-Nilssen, Bliddal, & Danneskiod-Samsøe, 2004). Thus, our results may provide a more accurate depiction of test reliability. However, as a result of the differing statistics used in the two studies, intra-rater reliability results in the current study cannot be directly compared with those reported by Cuberek et al. (2013).

Our review of the literature also could not identify any studies that directly compare the classic SR and V-SR to one another and we did not collect classic SR test data as part of this study. Thus, we do not know the validity of the V-SR in comparison to the "gold-standard" test (classic SR). However, because researchers have compared the classic SR and V-SR to the PSLR and Macrae & Wright tests, comparisons can be made between the two tests (Mayorga-Vega, et al., 2014). The validity of the classic SR for measuring hamstring flexibility has been found to be moderate to good, while the validity or the classic SR for measuring lumbar spine flexibility has been found to be poor to moderate (Mayorga-Vega, et al., 2014). In contrast, the validity of the V-SR has been found to be low to moderate for assessing both hamstring flexibility compared to the PSLR and lumbar spine flexibility compared to the Macrae &

Wright test (Hui & Yuen, 2000). Though the validity of both the classic SR and V-SR are low for measuring hamstring and lumbar spine motion specifically, the tests remain good for measuring overall flexibility of the lower extremity and spine (Mier & Sapiro, 2013). As clinicians and other professionals use the classic SR or V-SR, it is important to know and understand these tests have the ability to be measuring a number of structures within the body that are not isolated to hamstring musculature and lumbar spine mobility (Mier & Shapiro, 2013).

One of the limitations of the classic SR test is the cost of the specific box that is used. A classic SR box is commonly found to cost around $100 (Amazon.com). In contrast, a single V-SR test costs about $10 to purchase adhesive tape and a tape measure (MedCo-athletics.com). This is a benefit of the V-SR in any setting where budgets are limited and flexibility continues to be an integral component of physical education, pre-participation examination, or injury evaluations (Corbin & Noble, 1980). Additionally, the storage of the classic SR box can be problematic, whereas the V-SR storage is minimal. Although the classic SR is used universally, the V-SR is a practical and reliable alternative for measuring hamstring and low back motion. Additionally, these results can be applied for novice raters when using the V-SR test, meaning raters that are not experts with performing the V-SR can still maintain good reliability.

Limitations of this study include the use of a healthy population who was not suffering from injury or complaining of hamstring tightness. Thus, we do not know if the reliability of the test changes within an injured population or those who report perceptions of hamstring tightness. Another limitation is the use of health care professionals. Given their professional training, it is possible the raters could have increased reliability that is not found in other profession where the measurement of client or patient health measures is less commonly performed. However, given that all raters were novice clinicians to this test who did not regularly perform the classic SR, it may be reasonable to assume that other professionals can quickly learn to reliably use the V-SR test. Future research should be conducted to examine the validity of the V-SR as well as the correlation the various modifications of the SR test to further understand if the variations can be used interchangeably. Future researchers should also examine the validity of the V-SR test in correlation to other methods of assessing hamstring

flexibility and lumber flexibility. Additionally, further investigation should be performed using various populations (geriatric, young children, injured, etc.).

Conclusion

The V-SR is a reliable test between and within raters that have minimal experience with the V-SR. Physical educators or clinicians who have limited space, equipment, or budgets may find the V-SR to be a more viable option for use in their settings and that the V-SR test can be as, or more, reliably conducted than the classic SR test based on values available in the literature. Overall, the V-SR is a reliable test for novice raters both between and within raters and now has established SEM and MDC values that can increase purposeful use of the test in a variety of settings.

Figure 3.1: Setup of the V-SR with two tape boxes, Medco® Sports Medicine cloth tape measure (150cm), and Duck® Tape Beige General Purpose Masking Tape (18mm X 55m)

Figure 3.2: Starting position for V-SR with a clinician and an assistant stabilizing the participant's knees

Figure 3.3: Ending position for V-SR with a clinician and an assistant stabilizing the participant's knees throughout the movement

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CHAPTER 4 : CRITICALLY APPRAISED TOPICS (CATs)

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

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

Clinical Scenario

Hamstring tightness (HT), a common condition across all age groups[1], 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.[2] Recently, researchers have questioned the efficacy of stretching as a treatment method for increasing ROM compared to other techniques.[3]
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.[4] 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.[5,6,7] Several recent studies have examined the effectiveness of stretching compared to NDS.[5,6,7] 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 6 studies. Of the 6 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 4.2).
- All studies compared NDS targeting the sciatic nerve to stretching, with hamstring ROM measurements as a primary outcome measure. Both PNF[5] and static[6,7] 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[6] 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,[6] 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. The authors of one of the three studies[6] demonstrated NDS was more effective than static stretching at increasing hamstring ROM measurements, while the authors of a second study[7] reported no difference between NDS and static stretching. The authors of the third study[5] evaluated in the CAT 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 on participants with limited hamstring flexibility. The Strength of Recommendation Taxonomy[8] 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 4.1).

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 range of motion outcomes

Results of Search

Three relevant studies were located using the above search terms (Table 4.1). Validity of the selected studies was identified using the PEDro scale (Tables 4.2 & 4.3). 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 4.1, 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.[4] The "tightness" reported by the patient may be based on a perception of tightness, rather than a tissue length issue.[9] Addressing the neural component within the muscle tissue may result in increased measures of ROM.[4] Therefore, NDS s 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[6] available, researchers 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.[6] The findings were in contrast to those of researchers who conducted less rigorous studies[5,7] and found there was either no difference[7] or that stretching was more effective than NDS in the treatment of participants with apparent HT.[5] The researchers[5,6,7] who compared NDS directly to stretching, however, have not utilized consistent methodologies, which makes it difficult to assess outcomes across the limited evidence

available. 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 sliders.

The assessment methodology differed between the three studies. The active knee extension (AKE) was the method of assessment in one study[5] while the PSLR was utilized in the other studies[6,7] 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. Some researchers found that a single application of NDS was more effective at increasing ROM than static stretching[6] while others determined both NDS and static stretching significantly increased ROM equally following three sessions over a one week period.[7] Another group of researchers also used three treatment sessions, but had participants perform hold-relax PNF as the comparison treatment rather than static stretching.[5] 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, two researchers[5,7] used a seated position while the third[6] used a supine position. Similarly conflicting, overpressure was only used in one study,[5] 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.[10]

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 sciatic sliders 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 4.1: Search strategy

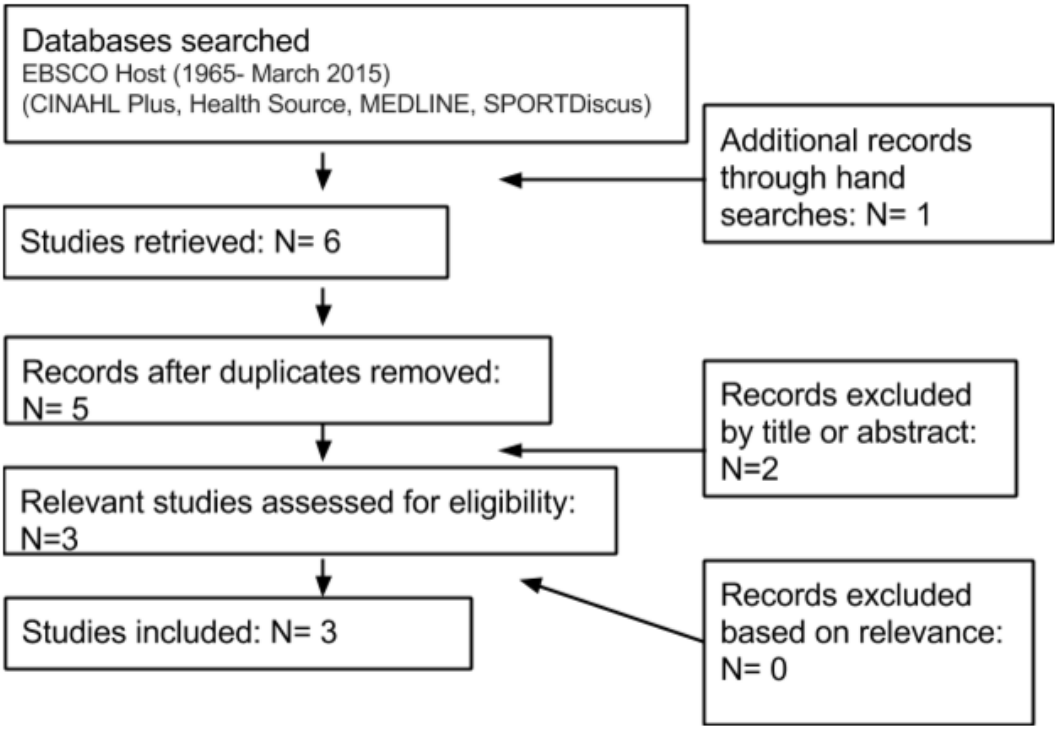

Table 4.1: Summary of Study Designs of Articles Retrieved

	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 4.2: 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 4.3: 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

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Castellote-Caballero Y, Valenza M, C E, et al. Immediate Effects of Neurodynamic Sliding versus Muscle Stretching on Hamstring Flexibility in Subjects with Short Hamstring Syndrome. *J Sports Med*. 2014;2014:e127471.

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

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.[1-3] Static stretching has been used for many years and requires the individual to lengthen the muscle to end range and hold this position for varying amounts of time.[4-6] Numerous studies have been performed to understand appropriate stretch duration; however, treatment application varies between five to 60 seconds.[4,7-9] Proprioceptive neuromuscular facilitation (PNF) stretching is another type of stretching used frequently to increase ROM.[5,10] A combination of contraction and relaxation of either agonist or antagonist muscles is used during PNF stretching.[5,6,10,11] 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.

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 range of motion gains. The previous systematic review was published in 2006, and included studies that were not exclusive to hamstring ROM.[12] Therefore, there was a need to critically appraise the literature regarding the effects of PNF and static stretching on hamstring ROM. 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 4.2).

Terms Used to Guide Search Strategy

- **P**atient/ Client group: Healthy adults with or without hamstring tightness
- **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)[5] or active knee extension (AKE)[6,10] 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 (Table 4.5). 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).[13]

Results of Search

Three relevant studies were located using the search terms identified in the *Search Strategy* section. As described in Table 4.5, 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 4.5).
- In all of the studies that met inclusion and exclusion criteria, PNF stretching was compared to static stretching, with hamstring range of motion measurements as a primary outcome measure. In one study, an additional comparison was made to active self-stretch.[5]
- In the three studies that met inclusion/exclusion criteria, hamstring tightness was determined by the AKE [6,10] or KEA.[5] Tight hamstrings are defined as 20° from vertical on the KEA[5] or AKE[6,10] 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 actively extend the knee[5, 10] or an examiner passively extended the knee to record the measurement.[6] The AKE[6,10] or KEA[5] measurements were recorded using a digital inclinometer[5,6] or a manual protractor.[10]
- The PEDro scores were obtained from the Physiotherapy Evidence Database. Although the studies selected for inclusion in this CAT were identified as the best

evidence, the average PEDro score for included articles was 4.33/10 which indicates low-quality evidence.

- Of the articles included, the authors of two studies[6,10] indicated that both PNF and static stretching resulted in significant gains on the AKE[6,10] with no significant difference between techniques; however, the authors of one study[5] 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[5] and five.[6,10] Areas such as eligibility criteria,[5,10] concealing allocation of subjects,[5,6] blinding (subjects/therapists),[5,6,10] follow-up,[5,6,10] and an intent to treat analysis[5,6,10] were non-existent in the majority of the articles leading to the lower PEDro scores (Table 4.6).

Clinical Bottom Line

For individuals with hamstring tightness, there is low quality evidence to suggest either PNF or static stretching are more effective at increasing ROM. The effectiveness of PNF stretching compared to static stretching is inconclusive. Researchers in one[5] of the three included studies found that static stretching was more effective than PNF stretching, while the other two groups of researchers determined that both methods were equally effective at increasing ROM measures in healthy individuals with tight hamstrings.

Strength of Recommendation

Grade D evidence exists 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 grade of D for troubling inconsistent or inconclusive studies as found within this CAT.[14]

Implications for Practice, Education, and Future Research

In the appraisal of the three included studies in this CAT, Davis et al.[5] found static stretching to be more effective at increasing KEA measurements than PNF-R (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-R stretch may facilitate the

hamstring muscles, limiting the muscles' ability to relax and elongate.[5,12] In contrast, Lim et al.[10] 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.[6] who compared similar stretch interventions.

The lack of significant findings between interventions could be attributed to the variance in methodology for both the static stretch and PNF stretching interventions. First, for the static stretch intervention, Lim et al.[10] and Puentedura et al.[6] performed a single treatment session consisting of one[10] or two[6] sets of 30 second stretches. Davis et al.[5] utilized two sets of 30 seconds performed three times per week for a duration of four weeks. Davis et al.[5] 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.[15-18]

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.[5] applied a passive straight leg raise (PSLR) to the point of a strong, but tolerable stretch sensation for the subject. Similarly, Lim et al.[10] also applied a PSLR; however, the stretch was applied to the point of light tolerable pain for the subject. Puentedura's et al.[6] methods were significantly different as they included a warm-up and may lack clinical relevance due to 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.[5] 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.[10] 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.[10] Additionally, Puentedura et al.[6] 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 based on the current literature. 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 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 range of motion; 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 4.2: Search Strategy

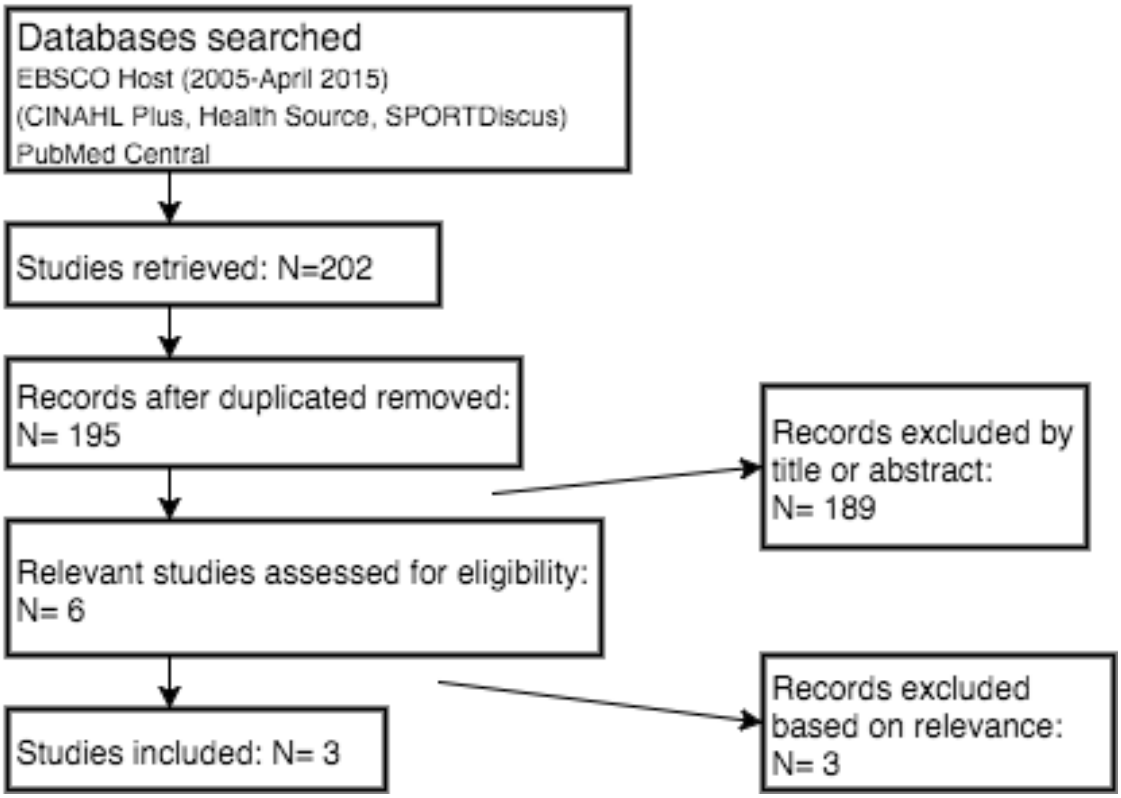

Table 4.4: Characteristics of Included Studies

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	Inclusion: 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. Exclusion: Previous history of lower-extremity pathology, which may adversely affect hamstring flexibility length.	Inclusion: Male adults in their 20s and 30s; Extensibility of hamstring muscle reduced by 20° as measured by the Active Knee Extension (AKE) Test. Exclusion: 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.	Inclusion: Not listed Exclusion: (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.	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.	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

	Group 3 (Proprioception Neuromuscular Facilitation (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.	Control Group: No intervention specified.	contraction with 10 second passive stretch intervals. 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 4.5: 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

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CHAPTER 5 : APPLIED CLINICAL RESEARCH

HAMSTRING EXTENSIBILITY FOLLOWING TOTAL MOTION RELEASE® FORWARD FLEXION TRUNK TWIST VERSUS SHAM TREATMENT

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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.

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 $\geq .2$, medium $\geq .5$, and large $\geq .8$.[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 ($\lambda = 0.9$, $F_{(2,55)} = 3.21$, $p = .048$, 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 ($\lambda = 0.31$, $F_{(2,26)} = 29.11$, $p < .001$, 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 (λ = 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	1.54cm	4.26cm
VSR	0.98	0.97, 0.99	1.40cm	3.89cm
AKE=active knee extension; CI=confidence interval; FFD=finger-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°±4.8°	2.7°±6.6°	0.018*	0.66, 6.8	5.0°±6.0°	2.6°±5.5°	0.105	-0.53, 5.5
Most restricted PSLR	5.8°±4.2°	2.2°±4.5°	0.002*	1.4, 6.0	4.4°±8.1°	1.0°±8.1°	0.115	-0.86, 7.7
FFD	4.6±3.4 cm	2.0±4.1cm	0.010*	0.67, 4.7	2.9±4.6cm	1.0±5.1cm	0.155	-0.73, 4.5
VSR	4.4±3.1 cm	1.7±2.9cm	0.001*	1.1, 4.3	2.2±3.3cm	-0.12±5.2cm	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)

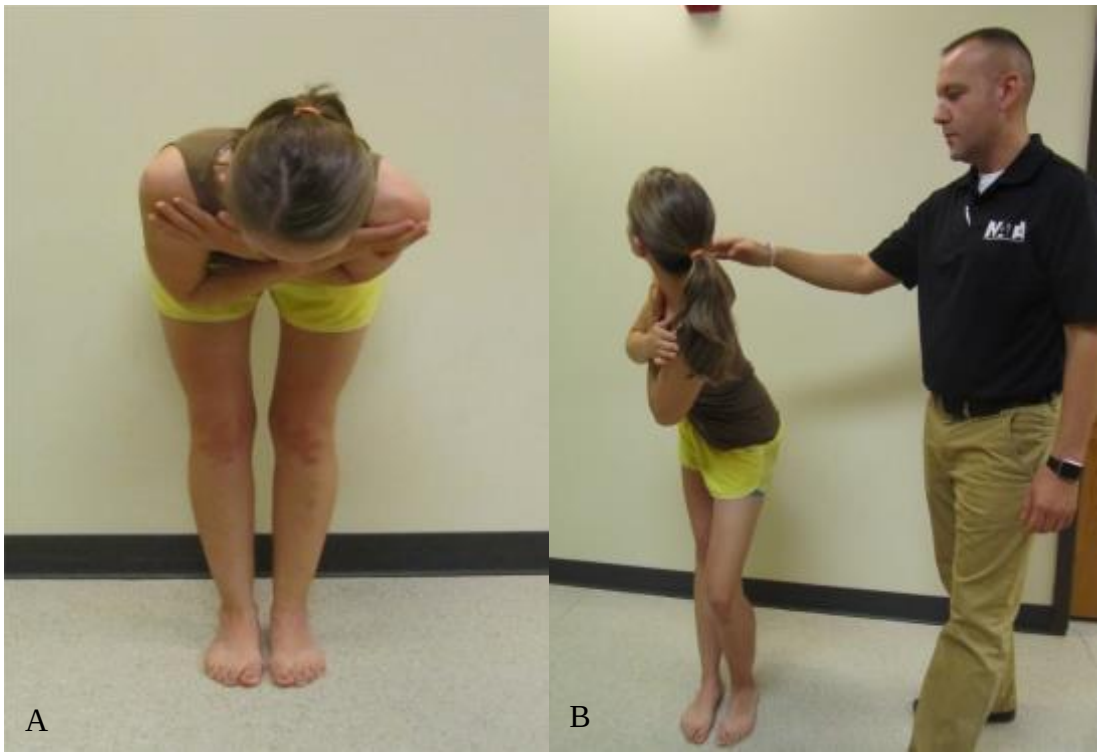


Figure 5.2: TMR® FFTT feet apart treatment

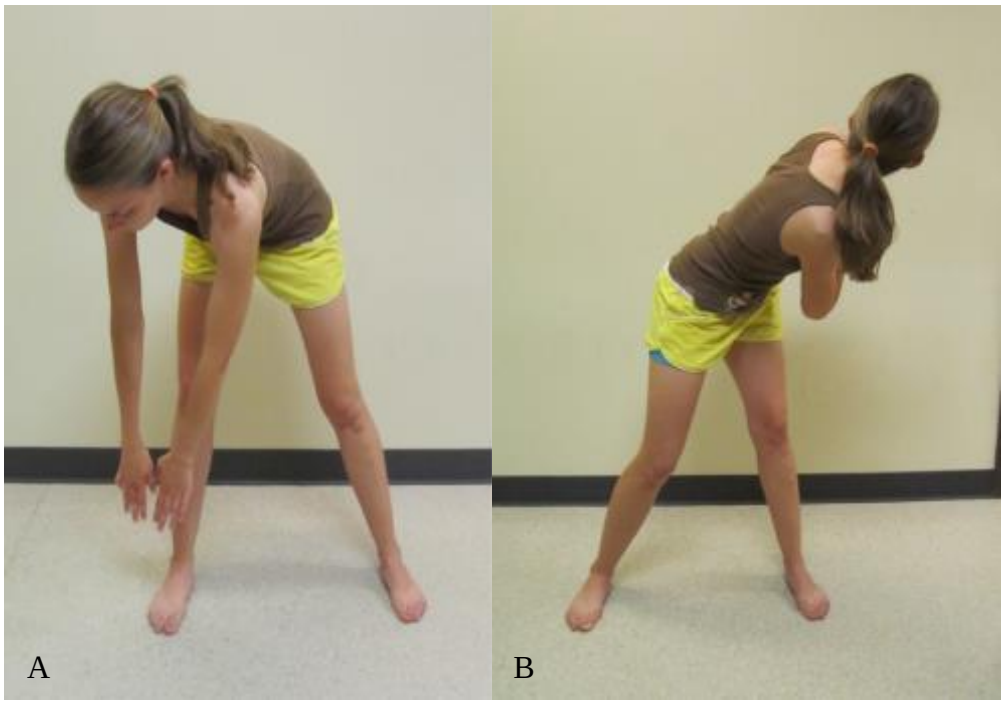


Figure 5.3: Active knee extension (AKE) assessment

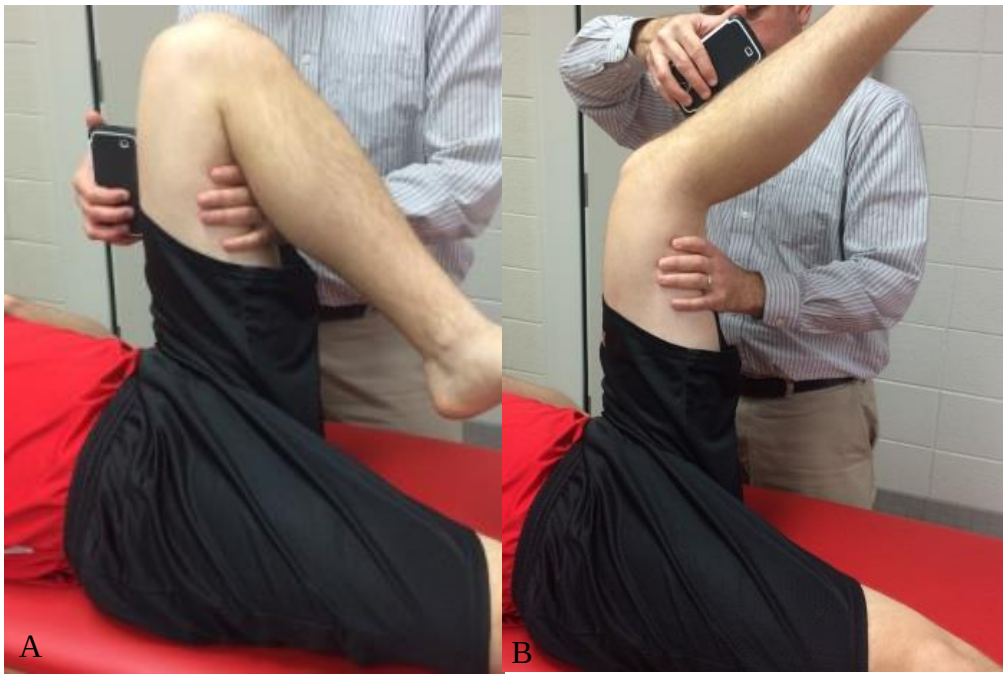


Figure 5.4: Passive straight leg raise (PSLR) assessment

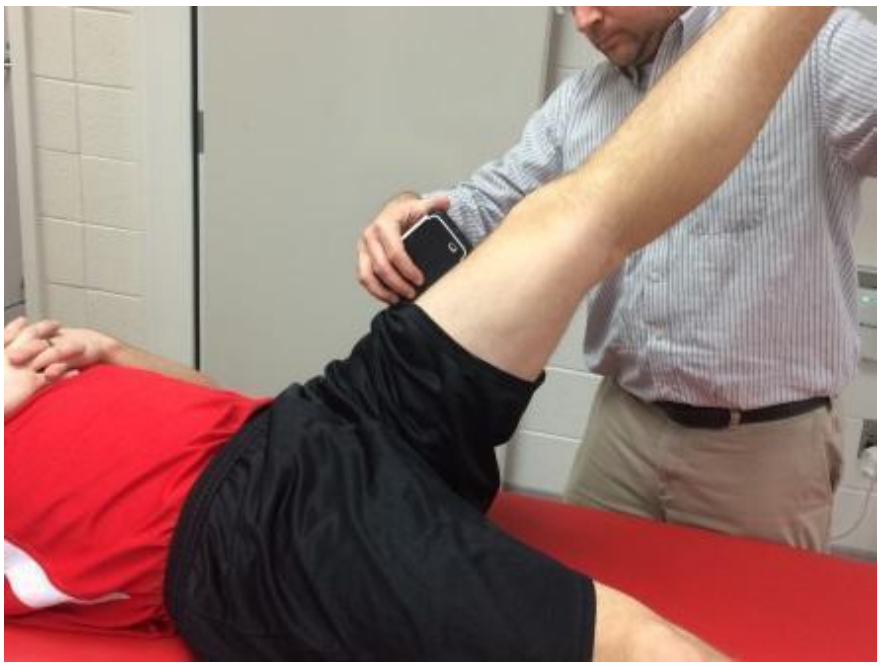


Figure 5.5: Finger to floor distance (FFD) assessment

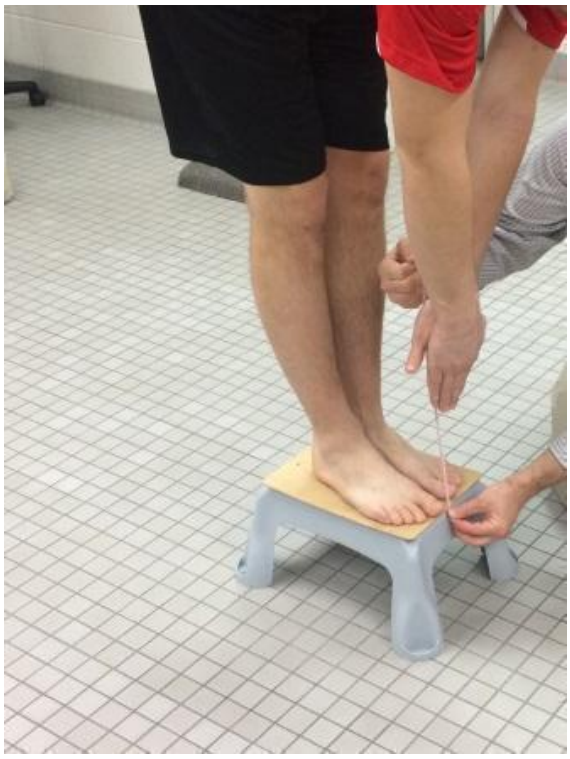
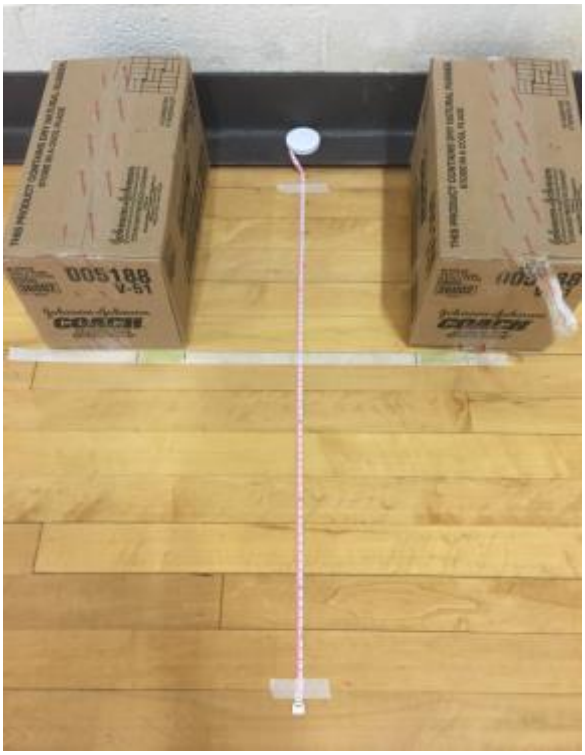


Figure 5.6: V-sit and reach (VSR) set-up



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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.

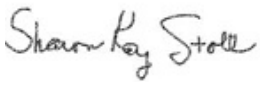
This IRB approval is not to be construed as authorization to recruit participants or conduct research in schools or other institutions, including on Native Reserved lands or within Native Institutions, which have their own policies that require approvals before Human Participants Research Projects can 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.



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