PULSED SHORT-WAVE DIATHERMY AND ITS INFLUENCE ON A PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION STRETCHING PROTOCOL OF THE HAMSTRINGS

By

BENJAMIN PATRICK VARILEK

Bachelor of Science in Exercise Science

University of Nebraska at Kearney

Kearney, Nebraska

2008

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2010

PULSED SHORT-WAVE DIATHERMY AND ITS INFLUENCE ON A PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION STRETCHING PROTOCOL OF THE HAMSTRINGS

Thesis Approved:

Dr. Blaine C. Long
Thesis Adviser

Dr. Suzanne M. Konz

Dr. Doug B. Smith

Dr. A. Gordon Emslie
Dean of the Graduate College

ACKNOWLEDGMENTS

I would like offer my deepest thanks to my family, friends, and colleagues who have helped make this process possible. Without their time, effort, generosity, and humor I could not have finished. First and foremost I would like to thank my parents for dealing with me for 24 years and not disowning me. They have taught me to never give up and to strive to be the best that I can be no matter what the obstacle.

Over the last two years I have been fortunate enough make several good friends who have helped to make this time memorable. I would especially like to thank my fellow graduate students and good friends Westin Kensinger, Brennan Thompson, Rachel Hildebrand, and Amanda Wheeler for their support and humor throughout this process. They were there to offer priceless advice and memories day in and day out. I would also like to thank the students of the OSU Athletic Training Program for many unforgettable experiences and for accepting me into their program.

I would like to sincerely thank Dr. Blaine Long for taking me under his wing and driving me throughout this process. He put in countless hours at all times of day to make sure I was headed in the right direction. I would also like to thank my "Life Coach" Dr. Suzie Konz for allowing me time to vent and keep me sane through all the difficult times.

Finally I would like to thank the members of my committee Dr.'s Blaine Long, Suzie Konz, and Doug Smith. Their guidance and support was essential in making this

thesis possible. All three of them gave me a solid view on my project and did anything they could to see that I succeeded.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Thermotherapy modalities are used to increase intramuscular temperature.[1] Associated with this increase in temperature, thermal modalities also increase tissue extensibility,[2, 3] blood flow,[4-6] and promote muscle relaxation,[1] thus allowing greater range of motion (ROM).[2, 7] One thermal modality commonly used to increase intramuscular temperature is pulsed short-wave diathermy (PSWD). Pulsed short-wave diathermy produces deep heat through the use of high-frequency electromagnetic energy.[1]

Many investigators have examined stretching techniques to determine which method is the most effective at increasing ROM. Three techniques commonly used include static, ballistic, and proprioceptive neuromuscular facilitation (PNF).[8, 9] Static stretching combined with PSWD has been suggested to increase ROM.[4, 7] Draper et al.[7] reported that hamstring flexibility increased more with static stretching following a PSWD treatment than compared to those who did not receive the treatment.

Proprioceptive neuromuscular facilitation stretching is one of the most effective forms of increasing ROM.[10, 11] It consists of voluntary contractions resulting in Golgi tendon organ (GTO) activation. Stimulation of GTO's causes a reflexive relaxation in the muscle resulting in either autogenic inhibition (i.e. muscle relaxation with increased tension) or reciprocal inhibition (i.e. muscle relaxation in the muscle opposing the muscle experiencing increased tension).

Controversy on the beneficial effects of PNF stretching exists.[12-16] It has been reported that a 3-week PNF stretching program does not improve ROM.[12] Others, however, report that PNF stretching provides greater increases in ROM than static or ballistic stretching.[13-16] For example, it was suggested that an 8 week PNF stretching protocol increased ROM and maximum knee flexion and extension torque.[17] With these discrepancies, it is possible that when examining a major muscle group, such as the hamstrings, greater ROM changes may occur immediately following a deep heat application with PSWD. The purpose of this study is to determine if PSWD prior to 3 PNF stretching protocols improves hamstring flexibility or muscular power.

RESEARCH HYPOTHESIS

1. A 20-minute pulsed short-wave diathermy application immediately prior to proprioceptive neuromuscular facilitation stretches will have greater range of motion increases than proprioceptive neuromuscular facilitation stretches alone.
2. There will be no differences in range of motion gains between each proprioceptive neuromuscular facilitation stretch.
3. There will be no differences in power production between the proprioceptive neuromuscular facilitation stretches.

DEFINITIONS OF TERMS

1. Healthy – Subject who does not have a neurological, cardiovascular, endocrine, or orthopedic condition. In addition, the subject is not currently diagnosed with an illness that would prevent them from receiving a PSWD treatment.
2. Proprioceptive Neuromuscular Facilitation – A combined movement pattern that uses neural stimulation to facilitate a proper muscle response.[18]
3. Proprioceptive Neuromuscular Facilitation Stretching – Techniques that incorporate muscle contraction with active or passive movements in multiple planes.[10]
4. Contract Relax – Clinician provides isotonic resistance against the antagonist muscles to allow full end range of motion. Patient then relaxes the muscle where the clinician moves the extremity passively into the agonist pattern to stretch the antagonist.[18]

5. Hold Relax – A maximal isometric contraction of the antagonist at the end range of the agonist. The agonist is then used actively without resistance to increase motion of the antagonist.[18]
6. Contract Relax with Agonist Contraction – This technique is similar to the Hold-Relax technique however, a concentric contraction of the agonist muscle is used in addition to the passive stretching component.[16]
7. Autogenic Inhibition – A protective mechanism provided by the Golgi tendon organ, in which a Golgi tendon organ stimulus facilitated by a sudden stretch causes a reflex activation of the antagonist and relaxation of the agonist.[18]
8. Reciprocal Inhibition – A protective mechanism provided by the Golgi tendon organ, in which a Golgi tendon organ stimulus facilitated by a sudden stretch causes a reflex activation of the agonist and relaxation of the antagonist.[18]

ASSUMPTIONS

1. Subjects will honestly answer questions on the pre-participation health history questionnaire.
2. Subjects will not be involved in another stretching program throughout data collection.
3. Subjects will perform maximal effort vertical jumps.

DELIMITATIONS

1. Passive hip range of motion will be measured.
2. Subjects will be free from any lower extremity injury or lower extremity surgery 6 months prior to data collection.

3. Subjects will not be taking over-the-counter or prescription medication for pain or any other illness.
4. Subjects will be lacking 90° of hip flexion with complete knee extension.
5. Subjects will not be pregnant.
6. Subjects will not have received surgery that involved the implantation of a metal plate in their involved leg.
7. Subjects will not have any neurological impairment including sensory or motor deficits.

LIMITATIONS

1. The investigator is aware which treatment subjects are receiving.

CHAPTER II

REVIEW OF LITERATURE

A limited number of investigators have focused on proprioceptive neuromuscular facilitation (PNF) in combination with pulsed short-wave diathermy (PSWD), a deep tissue heating modality. A review of literature includes multiple references that relate to stretching techniques and heat application. Specifically, the focus will be directed towards those used to increase hip joint range of motion (ROM) and power. Of this information, some authors combine stretching protocols with the use of thermotherapy modalities. The purpose of this literature review is to describe different stretching techniques, thermotherapy modalities, stretching and thermotherapy, and methods of measuring force.

STRETCHING

Flexibility has been recognized as an important factor in the prevention and rehabilitation of athletic injuries as well as athletic performance.[8, 9, 11, 15, 19] Increasing flexibility is considered to be a critical component in preventing musculotendinous strains.[20] Decreased hamstring flexibility is thought to be one predisposing factor for hamstring injuries or low back injuries.[20, 21] One approach to increase flexibility is stretching. Stretching is an effective intervention to increase flexibility.[22]

Three types of stretching commonly used to increase flexibility include ballistic, static, and proprioceptive neuromuscular facilitation stretching.[23]

Ballistic Stretching

Ballistic stretching is effective at increasing ROM. However, it is not commonly incorporated into rehabilitation because it involves a series of jerks and pulls on resistant skeletal muscle tissue.[24] Ballistic stretching is a technique that involves a rhythmic bouncing motion using the momentum of the extremity to lengthen the muscle.[23, 25] When used in a controlled manner, ballistic stretching usually does not cause muscle soreness unless the force generated by the motion is greater than the tissues extensibility.[24]

Static Stretching

Static stretching is an alternative method to ballistic stretching and is considered to be safer. It involves a more controlled method of stretching where the involved tissue is gradually moved into a lengthened position.[24] Static stretching is performed by slowly elongating the involved structures and holding them at the point just before patient discomfort.[23, 25, 26]

Proprioceptive Neuromuscular Facilitation

Proprioceptive Neuromuscular Facilitation (PNF) was developed to assist in the rehabilitation of patients with severe brain trauma.[27] It was first introduced in the early 1900's when Sherrington defined the basic concepts of neuromuscular facilitation and inhibition.[10, 28] Some of these concepts eventually led to the development of each PNF

stretching technique.[10] The use of these concepts shortened the time frame until a patient could return to a functional lifestyle.[27]

Proprioceptive Neuromuscular Facilitation is one of the most effective methods of flexibility training for increasing ROM.[10, 11] Proprioceptive Neuromuscular Facilitation consists of voluntary contractions to activate Golgi tendon organs (GTO). Stimulation of GTO's causes a reflexive relaxation in the muscle resulting in either autogenic inhibition or reciprocal inhibition. If the relaxation occurs in the same muscle that is experiencing the increased tension, it is termed autogenic inhibition.[10, 14, 16, 29] Autogenic inhibition consists of contracting the involved muscles immediately before a passive stretch is applied.[10] If the relaxation occurs in the muscle opposing the muscle experiencing the increased tension, it is defined as reciprocal inhibition.[10, 14, 16, 29] An example of reciprocal inhibition would be simultaneously contracting the agonist muscles (quadriceps) opposing the antagonist muscles (hamstrings) being stretched.[14] Proprioceptive Neuromuscular Facilitation, static, and ballistic stretching are all effective at increasing ROM.[10] However, numerous investigators have reported that PNF stretching techniques achieve greater gains in knee extension.[10, 14, 16, 30]

There are 3 PNF stretching techniques that are commonly used by health care professionals. The names used to describe these techniques vary between authors. The descriptions of these techniques also differ depending on author. Often, the same names are used for different techniques or different names are used to describe the same technique.[16] For our purposes, the 3 techniques will be referred to as hold relax, contract relax, and contract relax with agonist contraction.

The hold relax technique occurs with a passive prestretch of the antagonist muscle (hamstrings) to the point of tightness reported by the subject and held for 10 seconds[16, 30] (Figure 1).

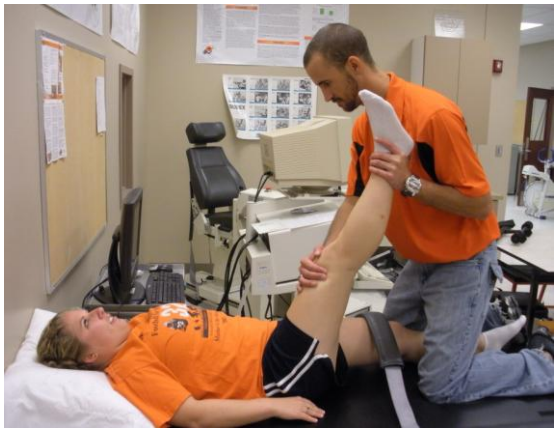

Figure 1. PNF Hold Relax Technique; Prestretch

The subject is then instructed to extend their hip towards the table while the examiner resists the movement resulting in an isometric contraction. This hip extension movement occurs for 6 seconds (Figure 2). The subject is directed to relax and a passive stretch is again performed and held for 30 seconds.

Figure 2. PNF Hold Relax Technique; Isometric Contraction

The contract relax technique also begins with a prestretch of the antagonist (hamstrings) to the point of tightness reported by the subject and held for 10 seconds.[16, 30] The patient extends their hip against the examiner's resistance through the full range of motion (Figure 3 and 4). The subject is instructed to relax and a passive stretch is again performed and held for 30 seconds.

Figure 3. PNF Contract Relax; Concentric Contraction Starting Position

Figure 4. PNF Contract Relax; Concentric Contraction Through Full ROM

The contract relax with agonist contraction technique begins with a passive prestretch of the antagonist muscle (hamstrings) to the point of tightness reported by the subject and held for 10 seconds.[16, 30] The subject is instructed to extend their hip while the examiner resists the movement resulting in an isometric contraction which is held for

6 seconds (Figure 5). The subject is then told to concentrically contract the agonist muscle (quadriceps) while relaxing the antagonist (hamstrings) and a passive stretch is applied to the antagonist for 30 seconds.

Figure 5. PNF Contract Relax with Agonist Contraction; Isometric Contraction

THERMOTHERAPY

Thermotherapy modalities are used to increase intramuscular temperature.[1] Associated with this increase in temperature, thermal modalities also increases tissue extensibility,[2, 3] blood flow,[4-6] and promote muscle relaxation,[1] thus potentially allowing greater range of motion (ROM).[2, 7] Thermotherapy modalities can be classified as deep tissue heating and superficial tissue heating.[1, 3] Modalities that can be used for increasing temperature are moist heat packs, ultrasound, and diathermy.

Superficial Heat

Superficial heating modalities most commonly include moist heat packs, warm whirlpool, and paraffin baths.[1, 24] These modalities increase intramuscular tissue temperature at a depth of under 2 centimeters (cm).[1] Moist heat packs can increase tissue temperature over a large area but, the depth of penetration is less than deep heating

modalities such as therapeutic ultrasound and diathermy.[3] The thermal effects of moist heat packs also begin to cool as soon as they are removed from their heating source,[3] thus we will not use them for this investigation.

Deep Heat

Deep heating modalities include continuous therapeutic ultrasound and diathermy. These modalities are capable of heating tissues at depths greater than 2 cm.[1, 31] Heating tissues at this depth is thought to decrease muscle spindle sensitivity during a stretch,[4] aid in muscle relaxation,[4, 32] and increase tissue extensibility.[4, 32, 33] Therapeutic ultrasound is only effective on a relatively small treatment area which should be no more than 2 times the size of the effective radiating area of the sound head (3-10 cm^2).[1, 31]

Diathermy is a deep tissue heating modality capable of heating tissues 3-5 centimeters deep.[1, 4, 31] One type of diathermy application is pulsed short-wave diathermy (PSWD). Pulsed short-wave diathermy produces deep heat through the use of high-frequency electromagnetic energy.[1] Advantages of using PSWD as compared to therapeutic ultrasound is the increased size of the treatment area.[1, 31] In addition to treatment area size, PSWD does not require a coupling agent like ultrasound and may be applied over clothing.[31] With its deep tissue heating, large treatment area, and constant rate of energy delivery, PSWD is the recommended thermal modality for the hamstrings.

Stretching and Thermotherapy

Stretching techniques are often used in conjunction with thermotherapy.[34] Knight et al.[25] compared the effects of superficial heat and deep heat on the extensibility of the ankle plantar flexors and reported that although superficial heat improved range of

motion (ROM) the deep heating group, which received ultrasound, had greater increases in ROM. They attributed the increase in ROM to the decrease in skeletal muscle spindle sensitivity which aids in muscle relaxation and tissue extensibility.[4, 32] Peres et al.[4] reported that deep heating combined with static stretching is more effective at increasing ROM than stretching alone. A more recent study by Draper et al.[7] supports the observation of Peres et al. It was suggested that deep heating increases ROM more so when combined with stretching than ROM gains of stretching alone.[7] It is also suggested that if tissue temperature is increased to 5°C the window of time for stretching on average is 3.3 minutes immediately following the deep heating treatment.[35] Due to this 3.3 minute time period, we will perform the stretching technique 3 times so as not to outlast the stretching window. An overview of relevant studies which examines the stretching techniques used and type of thermal treatment applied is presented in Table 1.

Table 1. Literature review of pertinent stretch techniques incorporating PNF, static, and dynamic methods with and without the use of thermotherapy

Author/Year	Stretch Type	Muscles tested	Heat applied?	Result
Williford & Smith 1985[9]	P.N.F.-H.R.& Static	Trunk, hip, & shoulder muscles (specific muscles not reported)	None applied	↑ R.O.M.: trunk-lateral flex, hip-flex/ext, hip- add/abd, shoulder flex/ext No diff. b/w P.N.F./static
Osternig et al. 1990[36]	P.N.F.-C.R., A.C.R., & Static	Hamstrings	None applied	↑ knee extension R.O.M. A.C.R. produced 9-13% more R.O.M. than static & P.N.F.-C.R.
Lentell et al. 1992[33]	Static	Shoulder internal rotators (specific muscles not reported)	Moist heat pack (66°C)	↑ shoulder external rotation R.O.M. R.O.M. ↑ w/ heat pack & stretch in first session
Cross & Worrell 1999[20]	Static	Hamstrings, Quadriceps, Hip Add., & Triceps Surae	None applied	↓ musculotendinous strains
Spernoga et al. 2001[11]	P.N.F.-H.R.	Hamstrings	None applied	↑ hip flexion R.O.M. Gains lasted 6 mins after 5th stretch
Burke et al. 2001[34]	P.N.F.-A.C.R.	Hamstrings	Hot bath (44°C) Cold bath (8°C)	↑ hip flexion R.O.M. No diff. in R.O.M. following hot or cold bath
Knight et al. 2001[25]	Static	Soleus	Hot pack (73.9°C) & 1 MHz 1.5W/cm^2 7 mins ultrasound	↑ ankle dorsiflexion R.O.M. Ultrasound ↑ R.O.M. over 6 weeks
Draper et al. 2002[32]	Static	Hamstrings	P.S.W.D. 7000 pps Pulse width 95 µsec	↑ hip flexion R.O.M. No diff. b/w P.S.W.D. & control
Peres et al. 2002[4]	Static	Ticeps Surae	P.S.W.D. 800 burst/sec & 400-µsec burst 48 W output	↑ ankle dorsiflexion R.O.M. PSWD & stretch ↑ R.O.M. more than stretch alone
Nelson & Bandy 2004[23]	Static & Eccentric	Hamstrings	None applied	↑ hip flexion R.O.M. No diff. b/w static or eccentric
Draper et al. 2004[7]	Static	Hamstrings	P.S.W.D. 800 burst/sec & 400-µsec burst 48 W output	↑ hip flexion R.O.M. P.S.W.D. ↑ was greater than sham, & control R.O.M. ↑ 5 consecutive days
Brucker et.al. 2005[37]	Static	Ticeps Surae	P.S.W.D. 800 burst/sec & 400-µsec burst 48 W output	↑ ankle dorsiflexion R.O.M. No diff. b/w P.S.W.D. w/ stretching & stretching

Table 1. Continued

Zakas et al. 2006[22]	Static	Rectus Femoris	None applied	↑ knee flexion R.O.M. Peak torque not affected
Yuktasir & Kaya 2007[29]	P.N.F.-C.R.& Static	Hamstrings & Ticeps Surae	None applied	↑ knee extension R.O.M. No diff. b/w P.N.F.-C.R. & static techniques Did not change drop jump results
Mitchell et al. 2007[13]	P.N.F.-C.R. & Static	Hamstrings	None applied	Stretch tolerance was greater w/ P.N.F. P.N.F. also had greatest ↑ in hip flexion R.O.M.
Bybee et al. 2008[26]	Static	Abdominals	None applied	↑ lumbar extension R.O.M. ↑ R.O.M. during 8 weeks
Manoel et al. 2008[19]	Static, Dynamic, & P.N.F.-C.R.	Quadriceps	None applied	Knee extension power had no diff. Dynamic had greatest percentage ↑ in power
Mitchell et al. 2009[14]	P.N.F-C.R. & A.C.R.	Hamstrings	None applied	↑ knee extension R.O.M. w/ hip at 90° Autogenic inhibition was not observed Reciprocal inhibition was not observed
Fasen et al. 2009[15]	P.N.F.-C.R. & Static	Hamstrings	None applied	↑ hip flexion R.O.M. Greatest ↑ w/ passive S.L.R. C.R. had greater ↑ than passive stretches except S.L.R.
Higgs & Winter 2009[17]	P.N.F.-C.R.	Quadriceps	None applied	↑ knee flexion R.O.M. No change in peak torque
O'Sullivan et al. 2009[21]	Static & Dynamic	Hamstrings	None applied	↑ knee extension R.O.M. w/ warm-up ↑ knee extension w/ static stretching ↓ knee extension w/ dynamic stretching

Abbreviation keys:

P.N.F. - Proprioceptive neuromuscular facilitation
H.R. - Hold relax
C.R. - Contract relax
A.C.R. - Agonist contract relax
P.S.W.D. - Pulsed short-wave diathermy
pps - pulses per second
S.L.R. - Straight leg raise
R.O.M. - Range of motion

METHODS OF MEASURING FORCE

Maximal voluntary isometric contraction (MVIC) is the maximal isometric force a person is capable of producing. During investigations of human skeletal muscle function involving MVIC, it is often reported that there is complete skeletal muscle activation during activity.[38] Two methods of assessing skeletal muscle activation are the interpolated twitch technique (ITT)[39-41] and central activation ratio (CAR).[38, 42]

Interpolated twitch technique

Interpolated twitch technique was first used by Merton[40] in 1954 to observe muscle inactivation. He initiated an electrical stimulus to the adductor pollicis muscle while subjects were performing a MVIC and an identical superimposed stimulus.[39, 40, 42] Since Merton, others have used ITT to asses skeletal muscle activation of the ankle dorsiflexors,[43] quadriceps,[39, 41] ankle plantarflexors,[39, 43] and elbow flexors.[44]

Central activation ratio

Central activation ratio is similar to ITT; however the electrical stimulus is delivered while a subject is performing a MVIC. Numerous investigators used the CAR method[38, 42, 45] during activity involving skeletal muscle failure.[38]

Interpolated Twitch Technique vs. Central Activation Ratio

In recent investigations,[41] it is reported that 2 or more stimuli should be delivered because changes in force are more readily detected.[46] Two potential issues with ITT are patient comfort and measurement sensitivity. Anecdotally, patients receiving the interpolated twitch technique experience more pain when the stimulus is delivered at rest. This pain may prevent an individual from producing maximal force. It is also reported

that a superimposed single or double stimulus is more tolerable than a train of stimuli: however, these stimuli may underestimate a maximal contraction.[38] It is therefore recommended that a train of stimuli using the CAR method be delivered.

Due to instrumentation required, time, and possible subject compliance we will not use the ITT or CAR methods. Instead, we will use a Tendo FitroDyne.

Tendo FitroDyne Setup

Setup for the Tendo FitroDyne system includes placing the subject in front of the machine with their feet shoulder width apart. The subject secures a belt around their waist which is attached to the Tendo FitroDyne cable. The subject then places their hands on their hips while the researcher ensures that the Tendo FitroDyne cable is centered between the subject's legs and perpendicular to the floor. The subject will then perform 3 maximal effort vertical jumps with 30 seconds of rest in-between repititions.

Subject Familiarization. Subjects who are not familiar with the Tendo FitroDyne system may not be accustomed to performing maximal effort vertical jumps. In order to limit potential inconsistencies, subjects will be allowed to perform some practice vertical jumps during a familiarization session (Figure 6).

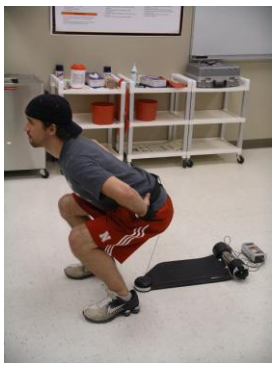

Figure 6. Subject Familiarization With Tendo FitroDyne

CHAPTER III

METHODS

Study Design

A 2 x 4 x 4 x 7 factorial with repeated measures on all factors guided data collection. The independent variables were treatment (PSWD or no PSWD), stretch type (contract relax, hold relax, contract relax with agonist contraction, and control), time (pretreatment (pre_{tx}), immediately posttreatment (post), 10-minutes posttreatment (10 min $post_{tx}$), and 20-minutes posttreatment (20 min post), and day (1, 2, 3, 4, 5, 6, 7). The dependent variables were hip flexion range of motion (ROM) and power.

Subjects

Thirty-five healthy college students with limited hamstring flexibility (ie. unable to achieve 90° of hip flexion) were recruited to participate in this study. One subject dropped out of the study so 34 subjects (male: n = 19, age = 22.89 ± 3.13 yrs, ht = 172.89 ± 6.30cm, mass = 77.84 ± 9.35 kg; female: n = 16, age = 20.44 ± 2.28 yrs, ht = 163.06 ± 6.06 cm, mass = 70.50 ± 10.94 kg) completed all requirements. Subjects had no history of lower extremity surgery or lower extremity injury of their dominant leg (ie. preferred leg for kicking a ball) in the past 6 months. Subjects were instructed to refrain from consuming sports supplements and any over-the-counter or prescription pain medication. Subjects were excluded if they were active in a sporting event, have pins, screws, or

metal implants in the involved limb, or pregnant. Each subject completed the health history questionnaire prior to signing the IRB informed consent form.

Subjects were randomly assigned a treatment group by selecting a number 1 or 2 from a hat. Each subject then drew another number from another hat to determine which stretching technique they received.

Instruments

A Megapulse II pulsed short-wave diathermy unit (Accelerated Care Plus, Reno, NV) with the following parameters: frequency = 27.12, 800pps, 400µsec (48 W) and delta 4 mode was used. The diathermy drum was applied directly to the hamstring muscle belly at a 90° angle. This was done to ensure that a majority of the electromagnetic waves were directed towards the hamstring muscle group (ie. Law of Cosine).

Muscle power was collected using a Tendo FitroDyne (Fitro-Dyne, Fitronic, Bratislava, Slovakia). The base of FitroDyne was placed on the floor behind the subject so that it did not interfere with the vertical jumping motion. The tether string was secured to the subjects waste with a via a belt. All hamstring flexibility measures were made using a Baseline bubble inclinometer (Fabrication Enterprises Inc., White Plains, NY).

Range of Motion Measures

Subjects laid supine on a padded table. The non-dominant leg was strapped to the table at the mid thigh region. A reference point was placed on the subjects tibial tuberosity with a permanent marker. This was done to ensure that the inclinometer was

located in the same place each time. Subjects were instructed to keep the permanent mark on their leg throughout the study. The involved leg was then passively flexed into hip flexion to the end range of motion.

Vertical Jump Test

Subjects stood with the string tether of the FitroDyne secured to a belt around the subjects waist. The subjects stood with their hands on their hips and feet shoulder width apart (Figure 7). Subjects squatted so that their knees and hips were flexed to 90° flexion.

Figure 7. Subject Positioning With Tendo FitroDyne

Three sub-maximal warm-up vertical jumps were then performed in order to acquaint each subject to the Tendo FitroDyne. Immediately following the warm-up, 3 maximum effort vertical jumps were performed with a 30 second rest between each jump.

Procedures

Testing occurred on 7 consecutive days. On each day, subjects reported to the laboratory at the same time of day dressed in shorts and a T-shirt. Subjects then removed their shoes and socks and lie supine on the padded table where their contralateral leg was

secured. Hip flexion ROM was then be measured by passively flexing the knee to the end ROM. Baseline muscle power measures were then calculated as previous described.

Following all baseline measures, subjects returned to the table and laid prone where they received PSWD or no PSWD (Figure 8). Following the treatment, subjects received 1 of the 4 PNF stretch types (contract relax, hold relax, contract relax with agonist contraction, or control). Immediately following, 10 minutes following, and 20 minutes following each stretch, ROM and power measures were recorded.

Figure 8. Placement of PSWD head for deep heat treatment

Statistical Analysis

We examined descriptive statistics for each treatment and stretch type across time for all 7 days. We then used separate factorial repeated measure ANOVA's to determine if ROM or muscular power were influenced by the treatment or stretch type across time and day. When significant main effect interactions were present, separate 2-way and 1-way ANOVA's were used. Tukey-Kramer multiple comparison post-hoc and 2-factor interactions were used to isolate individual differences. The alpha level was set at $P < .05$. Number crunchers statistical software (NCSS 2007, Kaysville, UT) was used to analyze all data.

CHAPTER IV

RESULTS

Our objective was to determine if PSWD prior to PNF stretching improves hamstring flexibility or muscular power. Data collection occurred over 7 days during the Spring 2010 semester from a sample of college students at Oklahoma State University.

Hypothesis 1

A 20-minute PSWD treatment immediately prior to 1 of 3 PNF stretches will have greater ROM increase than PNF stretching alone.

There was a significant 3-way interaction between treatment, stretch type, and time ($F_{9,178} = 2.07$; $P = .04$). There was also a significant 2-way interaction for treatment and day ($F_{6,150} = 2.36$; $P = .03$). Subjects who did not receive PSWD had greater ROM when they received the contract relax and contract relax w/ agonist contraction as compared to those receiving hold relax or the control ($F_{3, 917} = 36.21$; $P < .001$). Those who received PSWD prior to contract relax and hold relax had greater hip flexion ROM than those receiving contract relax w/ agonist contraction or control groups ($F_{1,917} = 25.81$; $P = .001$; Table 2). Those receiving PSWD on Days 2 and 5 had greater hip flexion ROM than those not receiving PSWD ($F_{6,150} = 2.36$; $P = .03$; Table 3).

Table 2. Range of motion for each treatment and stretch type (Means ± SD; n = 8 subjects)

Stretch Type	PSWD	No PSWD
Contract relax	92.48 ± 5.41[A]	89.46 ± 9.69[B]
Hold relax	88.85 ± 6.73[A]	85.45 ± 5.82[B]
Contract relax w/ agonist contraction	84.19 ± 10.26[A]	98.02 ± 9.23[B]
Control	85.96 ± 4.85[A]	79.41 ± 6.57[B]

[A] Contract relax w/agonist contraction and control < contract relax and hold relax
[B] Contract relax, hold relax, and control < contract relax w/ agonist contraction

Table 3. Range of motion for each treatment across all 7 days (Means ± SD; n = 8 subjects)

	PSWD	No PSWD
Day 1	82.76 ± 7.29[A]	82.78 ± 8.65[B, D]
Day 2	87.11 ± 7.13[A, E]	86.23 ± 9.64[C, D, E]
Day 3	86.86 ± 5.95[A]	87.32 ± 11.30[B]
Day 4	87.71 ± 6.70[A]	87.61 ± 10.81[B]
Day 5	88.21 ± 6.55[A, E]	87.83 ± 10.40[E]
Day 6	88.55 ± 6.43[A]	88.59 ± 9.28[B, C, D]
Day 7	88.84 ±10.06[A]	88.89 ± 10.06[B, C, D]

[A] Day 1 < 2, 3, 4, 5, 6, 7
[B] Day 1 < 3, 4, 6, 7
[C] Day 2 < 6, 7
[D] Day 1 and 2 < 6 and 7
[E] No Diathermy < Diathermy

Hypothesis 2

We hypothesized that there would be no differences in ROM between each PNF stretch type.

There was a significant 2-way interaction between stretch type and time ($F_{9,78}$ = 18.18; $P < .001$). Range of motion increased for those receiving contract relax, hold relax, and contract relax w/ agonist contraction (Tukey-Kramer, $P < .05$). Subjects receiving contract relax and contract relax w/ agonist contraction increased ROM more than those in the hold relax and control groups ($F_{3, 917}$ = 36.21; $P < .001$; Table 4).

Table 4. Range of motion for each stretch type across all 7 days (Means ± SD; n = 8 subjects)

	Contract relax	Hold relax	Contract relax w/ agonist contraction	Control
Day 1	84.31 ± 7.46[A]	83.80 ± 5.65[B]	83.37 ± 11.38[A, B]	81.05 ± 7.23
Day 2	89.87 ± 8.02[A, D]	87.21 ± 6.87[D]	88.50 ± 10.78[C, D]	82.63 ± 6.72[D]
Day 3	91.07 ± 8.59[A, D]	85.86 ± 6.41[D]	90.97 ± 13.06[D]	83.71 ± 6.14[D]
Day 4	90.72 ± 8.79[A, D]	88.22 ± 6.39[D]	90.95 ± 13.18[D]	83.98 ± 6.02[D]
Day 5	92.10 ± 9.66[A, D]	88.39 ± 6.93[D]	89.52 ±10.09[D]	83.94 ± 5.71[D]
Day 6	91.50 ± 7.42[A, D]	87.56 ± 5.26[D]	92.37 ± 11.24[C, D]	84.72 ± 5.10[D]
Day 7	91.80 ± 8.76[A, D]	89.36 ± 5.98[B, D]	93.21 ±11.11[C, D]	85.03 ± 6.60[D]

[A] Days 2, 3, 4, 5, 6 > 1
[B] Days 7 > 1
[C] Days 6 and 7 > 2
[D] Contract relax, hold relax, contract relax w/ agonist contraction > control

Hypothesis 3

We hypothesized that there would be no differences in muscular power production between each PNF stretch type.

There was a significant 2-way interaction for treatment and day ($F_{6,150}$ = 4.92; P = .001). There was no difference between treatment and stretch type ($F_{3,26}$ = 0.61; P = .61; Table 5) but here was a significant interaction between stretch type across all 7 days ($F_{6,150}$ = 2.36 P = .033; Table 6). Those in the hold relax group had less muscular power than those in the contract relax, contract relax w/ agonist contraction, and control groups (Tukey-Kramer P < .05; Table 6).

Table 5. Average power for each treatment and stretch type (Means ± SD; n = 8 subjects)

Stretch Type	PSWD	No PSWD
Contract relax	1321.98 ± 260.82	1545.25 ± 382.16
Hold relax	1165.51 ± 253.85	1504.35 ± 245.64
Contract relax w/ agonist contraction	1619.18 ± 267.68	1533.84 ± 148.92
Control	1646.45 ± 146.01	1663.55 ± 332.42

Table 6. Average power for each stretch type across all 7 days (Means ± SD; n = 8 subjects)

	Control relax	Hold relax	Contract relax w/agonist contraction	Control
Day 1	1450.26 ± 403.50[A, C]	1378.98 ± 317.61[A]	1578.67 ± 240.07[A]	1614.40 ± 248.27[A, C]
Day 2	1470.47 ± 387.53[A]	1357.22 ± 315.45[A]	1566.37 ± 210.95[A]	1628.74 ± 226.42[A, C]
Day 3	1456.48 ± 346.92[A, C]	1331.38 ± 270.67[A]	1590.86 ± 221.67[A]	1641.26 ± 230.24[A, C]
Day 4	1472.23 ± 359.23[A, C]	1340.08 ± 315.08[A]	1604.32 ± 228.09[A]	1649.78 ± 224.24[A, C]
Day 5	1488.28 ± 339.34[A, C]	1367.99 ± 286.15[A]	1584.02 ± 239.24[A]	1652.53 ± 234.59[A, C]
Day 6	1493.63 ± 365.65[B,C]	1279.22 ± 300.22[B]	1581.66 ± 224.80[B]	1690.21 ± 238.67[B, C]
Day 7	1534.65 ± 347.01[B,C]	1380.07 ± 279.79[B]	1582.80 ± 244.66[B]	1691.80 ± 209.48[B, C]

[A] Hold relax < contract relax < contract relax w/agonist contraction and control
[B] Hold relax < contract relax, contract relax w/agonist contraction, and control
[C] Contract relax < control

CHAPTER V

CONCLUSION

PNF stretching, was used in this study because it was found to be one of the most effective methods of flexibility training for increasing ROM.[10, 11] In regards to ROM, our observations support earlier research[11, 13, 36] where PNF stretch techniques were reported to be an effective way of increasing hip flexion ROM.

To determine if PSWD prior to PNF stretching improves hamstring flexibility or muscular power we hypothesized that a 20-minute PSWD treatment prior to PNF stretching would have greater hip flexion ROM than PNF stretching alone. This hypothesis was based on previous reports that increasing intratissue temperature leads to increases in tissue extensibility,[2, 3] blood flow,[4-6] and promotes muscle relaxation,[1] thus allowing greater range of motion (ROM).[2, 7]

With no differences in hip flexion ROM occurring between PSWD and no PSWD it appears that thermal effects from the treatment do not influence range of motion as measured following PNF stretching. When examining subjects receiving PSWD, however, greater hip flexion range of motion following the contract relax and hold relax stretching techniques occurred. This increased ROM may be associated with a neurophysiological mechanisms following the 3 sets of stretches in the contract relax or the hold relax groups. On the other hand, those in the contract relax with agonist contraction may have experienced co-contraction of the hamstrings and quadriceps muscles during the stretching protocol. This co-contraction which has been observed by others[14] may be responsible for the decrease in hip flexion range of motion.

These results disagree with Osternig et al.[36] who reported that the contract relax w/ agonist contraction provides greater ROM that contract relax. They inferred that any decrease in muscle activity may not be related to an observed increase in ROM. These differences may be associated with the subject population or ROM measures. As part of our inclusion criteria, subjects had to maintain their activities of daily living but had to have less than 90° of hip ROM. Osternig et al.[36] examined intercollegiate athletes where limitations in ROM were not reported.

Proprioceptive neuromuscular facilitation stretching should be taken into consideration when incorporating a PSWD treatment. By applying the standard 20-minute PSWD treatment, ROM was maintained for up to 20-minutes following the application. This supports a previous report on the stretching window following a PSWD treatment.[47] It is recommended that all stretch techniques be applied within 10 minutes following a standard stretch so that thermal benefits are maintained.

Pulsed short-wave diathermy did not influence power production as measured with the vertical jump test. These results support previous report by Manoel et al.[19] and Zakas et al.[22] who reported that knee extension power was not influenced by stretching. When examining each stretch across all days, subjects receiving hold relax had the lowest average power. These results contradict Manoel et al.[19] and Higgs and Winter[17] who observed no change in power production following a contract relax stretching protocol. This decrease in power production may be associated with the length tension relationship following the hold relax stretch protocol.

Conclusions

From the analysis it can be concluded that:

1. There is no significant difference in hip flexion range of motion gains between the 3 PNF stretch types. When incorporating PSWD contract relax and hold relax yielded the greatest increases in range of motion.
2. Regardless of PNF stretch type, ROM gains where highest immediately post treatment and stretch.
3. Regardless if PSWD was applied, hold relax PNF stretching had a negative influence on average power production.

REFERENCES

1. Starkey C. *Therapeutic Modalities*. 3rd ed. Philadelphia: F.A. Davis Company; 2004.

2. Cameron MH. *Physical Agents In Rehabilitation: From Research To Practice* 2nd ed. Philadelphia: Elsevier Science; 2003.

3. Robertson VJ, Ward AR, Jung P. The effect of heat on tissue extensibility: a comparison of deep and superficial heating. *Arch Phys Med Rehabil.* 2005;86(4):819-825.

4. Peres SE, Draper DO, Knight KL, Ricard MD. Pulsed shortwave diathermy and prolonged long-duration stretching increase dorsiflexion range of motion more than identical stretching without diathermy. *J Athl Train.* 2002;37(1):43-50.

5. Lehmann JF, Masock AJ, Warren CG, Koblanski JN. Effect of therapeutic temperatures on tendon extensibility. *Arch Phys Med Rehabil.* 1970;51(8):481-487.

6. Lehmann JF, Warren CG, Scham SM. Therapeutic heat and cold. *Clin Orthop.* 1974;99:207-245.

7. Draper DO, Castro JL, Feland B, Schulthies S, Eggett D. Shortwave diathermy and prolonged stretching increase hamstring flexibility more than prolonged stretching alone. *J Orthop Sports Phys Ther.* 2004;34(1):13-20.

8. Knappstein A, Stanley S, Whatman C. Range of motion immediately post and seven minutes post, PNF stretching: hip joint range of motion and PNF stretching. *NZJSM.* (2):42-46.

9. Williford HN, Smith JF. A comparison of proprioceptive neuromuscular facilitation and static stretching techniques. *Amer Corr Ther J.* 1985;39(2):30-33.

10. Sharman MJ, Cresswell AG, Riek S. Proprioceptive neuromuscular facilitation stretching mechanisms and clinical implications. *Sports Med.* 2006;36(11):929-939.

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

12. Worrell TW, Smith TL, Winegardner J. Effect of hamstring stretching on hamstring muscle performance. *J Orthop Sports Phys Ther.* 1994;20(3):154-159.

13. Mitchell UH, Myrer JW, Hopkins JT, Hunter I, Feland JB, Hilton SC. Acute stretch perception alteration contributes to the success of the PNF "contract-relax" stretch. *J Sport Rehabil.* 2007;16(2):85-92.

14. Mitchell UH, Myrer JW, Hunter I, Feland JN, Hilton SC. Neurophysiological reflex mechanisms' lack of contribution to the success of PNF stretches. *J Sport Rehabil.* 2009;18(3):343-357.

15. Fasen JM, O'Connor AM, Schwartz SL, Watson JO, Plastaras CT, Garvan CW, Bulcao C, Johnson SC, Akuthota V. A randomized controlled trial of hamstring stretching: comparison of four techniques. *J Strength Cond Res.* 2009;23(2):660-667.

16. Holcomb WR. Improved stretching with proprioceptive neuromuscular facilitation. *J Strength Cond Res.* 2000;22(1):59-61.

17. Higgs F, Winter SL. The effect of a four-week proprioceptive neuromuscular facilitation stretching program on isokinetic torque production. *J Strength Cond Res.* 2009;23(5):1442-1447.

18. Houglum PA. *Therapeutic Exercise For Musculoskeletal Injuries*. 2nd ed: Edwards Brothers, Inc.; 2005.

19. Manoel ME, Harris-Love MO, Danoff JV, Miller TA. Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. *J Strength Cond Res.* 2008;22(5):1528-1534.

20. Cross KM, Worrell TW. Effects of a static stretching program on the incidence of lower extremity musculotendinous strains. *J Athl Train.* 1999;34(1):11-14.

21. O'Sullivan K, Murray E, Sainsbury D. The effect of warm-up, static stretching and dynamic stretching on hamstring flexibility in previously injured subjects. *BMC Musculoskelet Disord.* 2009;10(37). Published Last Modified Date|. Accessed Dated Accessed|.

22. Zakas A, Galazoulas C, Doganis G, Zakas N. Effect of two acute static stretching durations of the rectus femoris muscle on quadriceps isokinetic peak torque in professional soccer players. *Isokinet Exerc Sci.* 2006;14:357-362.

23. Nelson RT, Bandy WD. Eccentric training and static stretching improve hamstring flexibility of high school males. *J Athl Train.* 2004;39(3):254-258.

24. Prentice WE. *Arhneim's Principles of Athletic Training A Competency-Based Approach*. 11th ed. New York: McGraw-Hill; 2003.

25. Knight CA, Rutledge CR, Cox ME, Costa MA, Hall SJ. Effect of superficial heat, deep heat, and active exercise warm-up on the extensibility of the plantar flexors. *Phys Ther*. 2001;81(6):1206-1214.

26. Bybee RF, Mamantov J, Meekins W, Witt J, Byars A, Greenwood M. Comparison of two stretching protocols on lumbar spine extension. *J Back Musculoskeletal Rehabil.* 2008;21(3):153-159.

27. Ferber R, Gravelle DC, Osternig LR. Effect of proprioceptive neuromuscular facilitation stretch techniques on trained and untrained older adults. *J Aging Phys Act.* 2002;10:132-142.

28. Sherrington CS. On plastic tonus and proprioceptive reflexes. *Q J Exp Physiol.* 1908;2(2):109-156.

29. Yuktasir B, Kaya F. Investigation into the long-term effects of static and PNF stretching exercises on range of motion and jump performance. *J Body Mov Ther.* 2007;13(1):11-21.

30. Surburg PR, Schrader JW. Proprioceptive neuromuscular facilitation techniques in sports medicine: a reassessment. *J Athl Train.* 1997;32(1):34-39.

31. Seiger C, Draper DO. Use of pulsed shortwave diathermy and joint mobilization to increase ankle range of motion in the presence of surgical implanted metal: a case series. *J Orthop Sports Phys Ther.* 2006;36(9):669-677.

32. Draper DO, Miner L, Knight KL, Ricard MD. The carry-over effects of diathermy and stretching in developing hamstring flexibility. *J Athl Train.* 2002;37(1):37-42.

33. Lentell G, Hetherington T, Eagan J, Morgan M. The use of thermal agents to influence the effectiveness of a low-load prolonged stretch. *J Orthop Sports Phys Ther* 1992;16(5):200-207.

34. Burke DG, Holt LE, Rasmussen R, MacKinnon NC, Vossen JF, Pelham TW. Effects of hot or cold water immersion and modified proprioceptive neuromuscular facilitation flexibility exercise on hamstring length. *J Athl Train.* 2001;36(1):16-19.

35. Draper DO, Ricard MD. Rate of temperature decay in human muscle following 3 MHz ultrasound: the stretching window revealed. *J Athl Train.* 1995;30(4):304-307.

36. Osternig LR, Robertson RN, Troxel RK, Hansen P. Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch techniques. *Med Sci Sports Exerc.* 1990;22(1):106-111.

37. Brucker JB, Knight KL, Rubley MD, Draper DO. An 18-day stretching regimen, with or without pulsed, shortwave diathermy, and ankle dorsiflexion after 3 weeks. *J Athl Train.* 2005;40(4):276-280.

38. Kent-Braun JA, Blanc RL. Quantitation of central activation failure during maximal voluntary contractions in humans. *Muscle Nerve.* 1996;19:861-869.

39. Behm DG, St-Pierre DMM, Perez D. Muscle inactivation: assessment of interpolated twitch technique. *J Appl Physiol.* 1996;81(5):2267-2273.

40. Merton PA. Voluntary strength and fatigue. *J Physiol.* 1954;123(3):553-564.

41. Behm D, Power K, Drinkwater E. Comparison of interpolation and central activation ratios as measures of muscle inactivation. *Muscle Nerve.* 2001;24(7):925-934.

42. Bampouras TM, Reeves ND, Baltzopoulos V, Maganaris CN. Muscle activation assessment: effects of method, stimulus number, and joint angle. *Muscle Nerve.* 2006;34(6):740-746.

43. Belanger AY, McComas AJ. Extent of motor unit activation during effort. *J Appl Physiol.* 1981;51(5):1131-1135.

44. Jakobi JM, Rice CL. Voluntary muscle activation varies with age and muscle group. *J Appl Physiol.* 2002;93(2):457-462.

45. Mizner RL, Peterson SC, Stevens JE, Vandenborne K, Snyder-Mackler L. Early quadriceps strength loss after total knee arthroplasty. *J Bone Joint Surg.* 2005;87-A(5):1047-1053.

46. Williams DM, Bilodeau M. Assessment of voluntary activation by stimulation of one muscle or two synergistic muscle. *Muscle Nerve.* 2003;29(1):112-119.

47. Draper DO, Knight K, Fujiwara T, Castel JC. Temperature change in human muscle during and after pulsed short-wave diathermy. *J Orthop Sports Phys Ther.* 1999;29(1):13-22.

APPENDICES

APPENDIX A

Sub #	Age	Ht (in)	Ht (cm)	Mass (kg)	Gend	TX	Stretch Type
1	19	66.5	169	69	M	1	3
2	23	72	183	83	M	2	2
3	19	68.1	173	89	M	2	2
4	20	70.08	178	88	M	1	1
5	22	64.2	163	62	M	2	2
6	19	62.6	159	60	F	1	2
7	19	62.60	159	72	F	1	3
8	21	63.39	161	60	F	2	1
9	22	68.90	175	76	M	2	3
10	26	58.27	148	61	F	1	3
11	20	65.35	166	82	F	1	1
12	25	67.72	172	80	M	1	3
13	25	69.29	176	80	M	2	4
14	19	65.35	166	70	F	1	1
15	20	68.11	173	74	M	2	2
16	20	63.78	162	59	F	2	1
17	20	68.50	174	68	F	2	4
18	25	64.57	164	75	M	2	4
19	29	64.57	164	83	M	2	1
20	30	70.47	179	94	M	2	4
21	22	63.78	162	61	M	2	2
22	24	62.60	159	65	F	1	1
23	21	68.50	174	74	F	2	4
24	19	63.78	162	49	F	1	2
25	24	67.72	172	94	M	2	1
26	21	67.32	171	81	M	1	3
27	23	68.50	174	68	M	1	4
28	19	64.17	163	87	F	2	1
29	19	63.78	162	85	F	2	3
30	24	64.57	164	75	F	2	1
31	19	64.57	164	82	F	1	4
32	18	65.35	166	79	F	1	4
33*	22	72.05	183	84	M	1	2
34	25	70.08	178	70	M	1	4
35	19	69.29	176	75	M	1	4

Stretch Type
1 = Contract Relax
2 = Hold Relax
3 = Contract Relax w/ Agonist Contraction
4= Control

Treatment
1 = PSWD
2 = No PSWD
*Subject was dropped from data collection

APPENDIX B

Table 2. Range of motion for each treatment and stretch type (Means ± SD; n = 8 subjects)

Stretch Type	PSWD	No PSWD
Contract Relax	92.48 ± 5.41[A]	89.46 ± 9.69[B]
Hold Relax	88.85 ± 6.73	85.45 ±5.82[B]
Contract Relax w/ Agonist Contraction	84.19 ± 10.26[A]	98.02 ± 9.23[B]
Control	85.96 ± 4.85[A]	79.41 ± 6.57[B]

[A] Contract Relax w/ Agonist Contraction and Control < Contract Relax and Hold Relax
[B] Contract Relax w/ Agonist Contraction > Contract Relax, Hold Relax, and Control

Table 3. Range of motion for each treatment and day (Means ± SD; n = 8 subjects)

	PSWD	No PSWD
Day 1	82.76 ± 7.29[A]	82.78 ± 8.65[B, D]
Day 2	87.11 ± 7.13[A, E]	86.23 ± 9.64[C, D, E]
Day 3	86.86 ± 5.95[A]	87.32 ± 11.30[B]
Day 4	87.71 ± 6.70[A]	87.61 ± 10.81[B]
Day 5	88.21 ± 6.55[A, E]	87.83 ± 10.40[E]
Day 6	88.55 ± 6.43[A]	88.59 ± 9.28[B, C, D]
Day7	88.84 ±10.06[A]	88.89 ± 10.06[B, C, D]

[A] Day 1 < 2, 3, 4, 5, 6, 7
[B] Day 1 < 3, 4, 6, 7
[C] Day 2 < 6, 7
[D] Day 6 and 7 > 1 and 2
[E] PSWD > No PSWD

Table 4. Range of motion for each stretch type across all 7 days (Means ± SD; n = 8 subjects)

	Contract Relax	Hold Relax	Contract Relax w/ Agonist Contraction	Control
Day 1	84.31 ± 7.46[A]	83.80 ± 5.65[A]	83.37 ± 11.38[A,B]	81.05 ± 7.23
Day 2	89.87 ± 8.02[A, D]	87.21 ± 6.87	88.50 ± 10.78[C]	82.63 ± 6.72[D]
Day 3	91.07 ± 8.59[A, D]	85.86 ± 6.41	90.97 ± 13.06	83.71 ± 6.14[D]
Day 4	90.72 ± 8.79[A, D]	88.22 ± 6.39	90.95 ± 13.18[A, B]	83.98 ± 6.02[D]
Day 5	92.10 ± 9.66[A, D]	88.39 ± 6.93	89.52 ±10.09	83.94 ± 5.71[D]
Day 6	91.50 ± 7.42[A, D]	87.56 ± 5.26	92.37 ± 11.24[B, C]	84.72 ± 5.10[D]
Day 7	91.80 ± 8.76[A, D]	89.36 ± 5.98[A]	93.21 ±11.11[B, C]	85.03 ± 6.60[D]

[A] Days 2, 3, 4, 5, 6 > 1 < 7 and 4
[B] Days 7 > 1
[C] Days 6 and 7 > 2
[D] Contract Relax > Control

Table 5. Range of motion on each of the 7 days across time (Means ± SD; n = 8 subjects)

	Pre	Post	10 min post	20 min post
Day 1	78.77 ± 7.25[A, B, C, G]	86.48 ± 7.81[A, D, G]	83.87 ± 7.68[A, B, C, G]	82.01 ± 7.05[A, C, D, G]
Day 2	82.18 ± 6.53[A, C, G]	90.33 ± 9.30[A, D, G]	87.59 ± 8.26[A, B, C, E, G]	85.29 ± 7.56[A, C, D, F, G]
Day 3	83.55 ± 6.22[A, C, G]	90.87 ± 9.92[A, D, G]	88.49 ± 9.09[A, C, G]	86.36 ± 8.88[A, C, D, G]
Day 4	84.39 ± 5.89[A, B, C, G]	90.62 ± 10.174[A, G]	88.80 ± 9.36[A, C, E, G]	86.65 ± 8.76[A, C, F, G]
Day 5	84.19 ± 6.46[A, B, C, G]	90.95 ± 9.56[A, D, G]	88.79 ± 8.90[A, C, G]	87.28 ± 8.19[A, C, D, F, G]
Day 6	85.44 ± 5.51[A, B, G]	91.56 ± 9.46[A, G]	89.67 ± 7.68[A, B, E, G]	87.69 ± 7.48[A, F, G]
Day 7	85.33 ± 6.09[A, B, G]	92.18 ± 9.41[A, G]	89.67 ± 8.91[A,B, E, G]	88.39 ± 8.75[A, F, G]

[A] Days 2, 3, 4, 5, 6 > 1 < 2, 6, 7
[B] Day 1 < 4, 5, 6, 7
[C] Day 1 < 2, 3, 4, 5
[D] Day 1 < 2, 3, 5
[E] Day 2 < 4, 6, 7
[F] Day 2 < 4, 5, 6, 7
[G] Pre < Post, 10 min post, 20 min post

Table 6. Analysis of variance for range of motion

Source	DF	SS	MS	F-Ratio	*P*-value	Power
A: Tx	1	1413.01	1413.01	1.03	0.32	0.17
B: Strch Type	3	5805.68	2836.21	2.07	0.13	0.47
AB	3	7351.71	2450.57	1.79	0.17	0.41
C(AB): Sub	26	35663.36	1371.67			
D: Time	3	6943.82	2314.61	204.13	0.001*	1.00
AD	3	23.88	7.96	0.70	0.55	0.19
BD	9	1855.04	206.12	18.18	0.001*	1.00
ABD	9	211.56	23.51	2.07	0.04*	0.83
CD(AB)	78	884.45	11.34			
E: Day	6	4108.90	684.82	20.26	0.001*	1.00
AE	6	479.13	79.85	2.36	0.03*	0.80
BE	18	861.49	47.86	1.42	0.13	0.87
ABE	18	667.22	37.07	1.10	0.36	0.74
CE(AB)	150	5069.39	33.80		0.	
DE	18	66.02	3.67	1.27	0.21	0.84
ADE	18	69.92	3.88	1.34	0.16	0.87
BDE	54	211.65	9.92	1.35	0.07	0.99
ABDE	54	205.71	3.81	1.31	0.08	0.99
CDE(AB)	447	1295.66	2.90			
S	0					
Total (Adjusted)	924	76233.53				
Total	925					

Table 7. Tukey-Kramer multiple-comparison of range of motion and treatment

Group	Count	Mean	Different From
PSWD	449	88.66	
No PSWD	476	86.00	

Table 8. Tukey-Kramer multiple-comparison of range of motion and stretch type

Group	Count	Mean	Different From
Contract Relax	279	89.66	
Hold Relax	173	86.62	
Contract Relax w/Agonist Contraction	193	90.24	
Control	280	82.81	

Table 9. Tukey-Kramer multiple-comparison of range of motion and time

Group	Count	Mean	Different From
Pre	232	82.26	Post; 10 min post; 20 min post
Post	231	91.30	Pre; 10 min post; 20 min post
10 min post	231	88.46	Pre; Post; 20 min post
20 min post	231	86.30	Pre; Post; 10 min post

Table 10. Tukey-Kramer multiple-comparison of range of motion and day

Group	Count	Mean	Different From
Day 1	136	82.90	Day 2, 3, 4, 5, 6, 7
Day 2	133	85.96	Day 1, 6, 7
Day 3	132	87.09	Day 1, 6, 7
Day 4	132	87.75	Day 1, 7
Day 5	132	87.91	Day 1, 7
Day 6	128	89.60	Day 1, 2, 3
Day 7	132	91.09	Day 1, 2, 3, 4, 5

Table 11. Two-way interaction of range of motion for each treatment across all stretch types

Group	Count	Mean	Different From
PSWD, Contract Relax	112	90.64	
PSWD, Hold Relax	61	91.79	
PSWD, Contract Relax w/Agonist Contraction	136	86.39	
PSWD, Control	140	85.81	
No PSWD, Contract Relax	167	88.67	
No PSWD, Hold Relax	112	81.45	
No PSWD, Contract Relax w/ Agonist Contraction	57	94.08	
No PSWD, Control	40	79.81	

Table 12. Two-way interaction of range of motion for each treatment across time

Group	Count	Mean	Different From
PSWD/Pre	113	84.83	PSWD/Post; PSWD/10 min post; PSWD/20 min post; No PSWD/Pre; No PSWD/Post; No PSWD/ 10 min post
PSWD/Post	112	92.54	PSWD/Pre; PSWD/10 min post; PSWD/20 min post; No PSWD/Pre; No PSWD/Post; No PSWD/ 10 min post; No PSWD/20 min post
PSWD/10 min post	112	89.84	PSWD/Pre; PSWD/Post; PSWD/20 min post; No PSWD/Pre; No PSWD/10 min post; No PSWD/ 20 min post
PSWD/20 min post	112	87.41	PSWD/Pre; PSWD/Post; PSWD/10 min post; No PSWD/Pre; No PSWD/Post; No PSWD/ 20 min post
No PSWD/Pre	119	81.68	PSWD/Pre; PSWD/Post; PSWD/10 min post; PSWD/20 min post; No PSWD/Post; No PSWD/ 10 min post; No PSWD/20 min post
No PSWD/Post	119	90.06	PSWD/Pre; PSWD/Post; PSWD/20 min post; No PSWD/Pre; No PSWD/10 min post; No PSWD/ 20 min post
No PSWD/10 min post	119	87.07	PSWD/Pre; PSWD/Post; PSWD/10 min post; No PSWD/Pre; No PSWD/Post; No PSWD/ 20 min post

Table 12. Continued

No PSWD/20 min post	119	85.19	PSWD/Post; PSWD/10 min post; PSWD/20 min post; No PSWD/Pre; No PSWD/Post; No PSWD/ 10 min post

Table 13. Two-way interaction for each stretch type across time

Group	Count	Mean	Different From
Contract Relax/ Pre	70	85.04	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/ 10 min post; Hold Relax/Pre; Hold Relax/Post; Hold Relax/ 10 min post; Contract Relax w/Agonist Contraction/Post; Contract Relax w/Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction /20 min post; Control/Pre; Control/ Post
Contract Relax/ Post	70	94.46	Contract Relax/Pre; Contract Relax/10 min post; Contract Relax/ 20 min post; Hold Relax/Pre; Hold Relax/Post; Hold Relax/ 10 min post Hold Relax/20 min post; Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction/20 min post; Control /Pre; Control/Post; Control/10 min post; Control/20 min post
Contract Relax/ 10 min post	70	91.04	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 20 min post; Hold Relax/Pre; Hold Relax/10 min post; Hold Relax/20 min post Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/Post; Control/Pre; Control/Post; Control/10 min post; Control/20 min post
Contract Relax/ 20 min post	69	88.08	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 10 min post; Hold Relax/Pre; Hold Relax/Post; Hold Relax/ 20 min post Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/Post; Contract Relax w/Agonist Contraction /10 min post; Control, Pre; Control/Post; Control/ 10 min post; Control/20 min post
Hold Relax/Pre	44	81.98	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 10 min post; Contract Relax/20 min post; Hold Relax/Post; Hold Relax/10 min post; Hold Relax/20 min post; Contract Relax w/ Agonist Contraction/Post; Contract Relax w/Agonist Contraction/ 10 min post; Contract Relax w/Agonist Contraction/20 min post
Hold Relax/Post	43	91.37	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 20 min post; Hold Relax/Pre; Hold Relax/10 min post; Hold Relax/20 min post Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/Post; Control/Pre; Control /Post; Control/10 min post; Control/20 min post
Hold Relax/10 min post	43	87.90	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 10 min post; Hold Relax/Pre; Hold Relax/Post; Hold Relax/ 20 min post Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/Post; Contract Relax w/Agonist Contraction /10 min post; Control/Pre; Control/Post; Control/ 10 min post; Control/20 min post
Hold Relax/20 min post	43	85.21	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/ 20 min post; Hold Relax/Pre; Hold Relax/Post; Hold Relax/ 10 min post Contract Relax w/Agonist Contraction/Post; Contract Relax w/Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction /20 min post; Control/Pre; Control/ 20 min post

Table 13. Continued

Contract Relax w/ Agonist Contraction/ Pre	48	84.00	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/ 20 min post; Hold Relax/Post; Hold Relax/10 min post; Contract Relax w/Agonist Contraction/Post; Contract Relax w/Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction/ 20 min post
Contract Relax w/ Agonist Contraction/ Post	48	95.70	Contract Relax/Pre; Contract Relax/10 min post; Contract Relax/ 20 min post; Hold Relax/Pre; Hold Relax/Post; Hold Relax/ 10 min post; Hold Relax/20 min post; Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction/20 min post; Control /Pre; Control/post; Control/10 min post; Control/20 min post
Contract Relax w/ Agonist Contraction/ 10 min post	48	91.75	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 20 min post; Hold Relax/Pre; Hold Relax/10 min post; Hold Relax/20 min post Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/Post; Control/Pre; Control/Post; Control/10 min post; Control/20 min post
Contract Relax w/ Agonist Contraction/ 20 min post	49	89.49	Contract Relax/Pre; Contract Relax/Post; Hold Relax/ Pre; Hold Relax/20 min post; Contract Relax w/Agonist Contraction/Pre; Contract Relax w/Agonist Contraction/Post; Control/Pre; Control/Post; Control/10 min post; Control/20 min post
Control/Pre	70	82.00	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 10 min post; Contract Relax/20 min post; Hold Relax/Post; Hold Relax/10 min post; Hold Relax/20 min post; Contract Relax w/ Agonist Contraction/Post; Contract Relax w/Agonist Contraction/ 10 min post; Contract Relax w/Agonist Contraction/20 min post
Control/Post	70	83.67	Contract Relax/Post; Contract Relax/10 min post; Contract Relax /20 min post; Hold Relax/Post; Hold Relax/10 min post; Contract Relax w/Agonist Contraction/Post; Contract Relax w/ Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction/20 min post
Control/10 min post	70	83.13	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/ 20 min post; Hold Relax/Post; Hold Relax/10 min post; Contract Relax w/Agonist Contraction/Post; Contract Relax w/Agonist Contraction/10 min post; Contract Relax w/Agonist Contraction/ 20 min post
Control/20 min post	70	82.43	Contract Relax/Pre; Contract Relax/Post; Contract Relax/ 10 min post; Contract Relax/20 min post; Hold Relax/Post; Hold Relax/10 min post; Hold Relax/20 min post; Contract Relax w/ Agonist Contraction/Post; Contract Relax w/Agonist Contraction/ 10 min post; Contract Relax w/Agonist Contraction/20 min post

Table 14. Two-way interaction of range of motion for each treatment across all 7 days

Group	Count	Mean	Different From
PSWD/Day 1	68	82.83	PSWD/Day 2; PSWD/Day 3; PSWD/Day 4; PSWD/Day 5; PSWD/Day 6; PSWD/Day 7; No PSWD/Day 3; No PSWD/Day 4; No PSWD/Day 6 No PSWD/Day 7
PSWD/Day 2	65	88.19	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2
PSWD/Day 3	64	87.78	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2
PSWD/Day 4	64	89.37	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2; No PSWD/Day 5

Table 14. Continued

PSWD/Day 5	64	89.96	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2; No PSWD/Day 3; No PSWD/Day 4; No PSWD/ Day 5
PSWD/Day 6	60	91.18	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2; No PSWD/Day 3; No PSWD/Day 4; No PSWD/ Day 5
PSWD/Day 7	64	91.28	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2; No PSWD/Day 3; No PSWD/Day 4; No PSWD/ Day 5
No PSWD/Day 1	68	82.98	PSWD/Day 2; PSWD/Day 3; PSWD/Day 4; PSWD/Day 5; PSWD/Day 6; PSWD/Day 7; No PSWD/Day 3; No PSWD/Day 4; No PSWD/Day 6; No PSWD/Day 7
No PSWD/Day 2	68	93.73	PSWD/Day 2; PSWD/Day 3; PSWD/Day 4; PSWD/Day 5; PSWD/Day 6; PSWD/Day 7; No PSWD/Day 6; No PSWD/Day 7
No PSWD/Day 3	68	86.45	PSWD/Day 1; PSWD/Day 5; PSWD/Day 6; PSWD/Day 7; No PSWD/Day 1
No PSWD/Day 4	68	85.83	PSWD/Day 1; PSWD/Day 5; PSWD/Day 6; PSWD/Day 7; No PSWD/Day 1
No PSWD/Day 5	68	85.53	PSWD/Day 4; PSWD/Day 5; PSWD/Day 6; PSWD/Day 7
No PSWD/Day 6	68	88.01	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2
No PSWD/Day 7	68	88.91	PSWD/Day 1; No PSWD/Day 1; No PSWD/Day 2

Table 15. Two-way interaction of range of motion for each stretch type across all 7 days

Group	Count	Mean	Different From
Contract Relax/Day 1	40	83.73	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 7; Contract Relax w/Agonist Contraction/Day 3; Contract Relax w/Agonist Contraction/ Day 4; Contract Relax w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/ Agonist Contraction/Day 7
Contract Relax/Day 2	40	88.82	Contract Relax/Day 1; Hold Relax/Day 1; Contract Relax w/ Agonist Contraction/Day 7; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6
Contract Relax/Day 3	40	90.18	Contract Relax/Day 1; Hold Relax/Day 1; Contract Relax w/ Agonist Contraction/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax/Day 4	40	89.63	Contract Relax/Day 1; Hold Relax/Day 1; Contract Relax w/ Agonist Contraction/Day 7; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax/Day 5	40	91.08	Contract Relax/Day 1; Hold Relax/Day 1; Contract Relax w/ Agonist Contraction/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax/Day 6	40	92.94	Contract Relax/Day 1; Hold Relax/Day 1; Hold Relax/Day 2; Hold Relax/Day 3; Hold Relax/Day 5; Contract Relax w/ Agonist Contraction/Day 1; Contract Relax w/Agonist Contraction/Day 2; Control/Day 1; Control/Day 2; Control/ Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control /Day 7

Table 15. Continued

Contract Relax/Day 7	39	91.22	Contract Relax/Day 1; Hold Relax/Day 1; Contract Relax w/ Agonist Contraction/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Hold Relax/Day 1	28	82.96	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 7; Contract Relax w/Agonist Contraction/Day 3; Contract Relax w/Agonist Contraction/ Day 4; Contract Relax w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/ Agonist Contraction/Day 7
Hold Relax/Day 2	25	85.92	Contract Relax/Day 6; Contract Relax w/Agonist Contraction/ Day 6; Contract Relax w/Agonist Contraction/Day 7
Hold Relax/Day 3	24	85.59	Contract Relax/Day 6; Contract Relax w/Agonist Contraction/ Day 6; Contract Relax w/Agonist Contraction/Day 7
Hold Relax/Day 4	24	87.31	Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/Agonist Contraction/Day 7; Control/Day 1
Hold Relax/Day 5	24	86.94	Contract Relax/Day 6; Contract Relax w/Agonist Contraction/ Day 6; Contract Relax w/Agonist Contraction/Day 7; Control/ Day 1
Hold Relax/Day 6	24	87.84	Contract Relax w/Agonist Contraction/Day 7; Control/Day 1; Control/Day 2
Hold Relax/Day 7	24	89.75	Contract Relax/Day 1; Hold Relax/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax w/ Agonist Contraction/ Day 1	28	84.55	Contract Relax/Day 3; Contract Relax/Day 5; Contract Relax/ Day 6; Contract Relax/Day 7; Contract Relax w/Agonist Contraction/Day 4; Contract Relax w/Agonist Contraction/ Day 6; Contract Relax w/Agonist Contraction/Day 7
Contract Relax w/ Agonist Contraction/ Day 2	28	87.26	Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/Agonist Contraction/Day 7; Control/Day 1
Contract Relax w/ Agonist Contraction/ Day 3	28	89.56	Contract Relax/Day 1; Hold Relax/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6
Contract Relax w/ Agonist Contraction/ Day 4	28	91.50	Contract Relax/Day 1; Hold Relax/Day 1; Contract Relax w/ Agonist Contraction/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax w/ Agonist Contraction/ Day 5	24	89.99	Contract Relax/Day 1; Hold Relax/Day 1; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax w/ Agonist Contraction/ Day 6	29	93.78	Contract Relax/Day 1; Hold Relax/Day 1; Hold Relax/Day 2; Hold Relax/Day 3; Hold Relax/Day 4; Hold Relax/Day 5; Contract Relax w/Agonist Contraction/Day 1; Contract Relax w/Agonist Contraction/Day 2; Control/Day 1; Control/Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/Day 6; Control/Day 7
Contract Relax w/ Agonist Contraction/ Day 7	40	95.01	Contract Relax/Day 1; Contract Relax/Day 2; Contract Relax/ Day 4; Hold Relax/Day 1; Hold Relax/Day 2; Hold Relax/ Day 3; Hold Relax/Day 4; Hold Relax/Day 5; Hold Relax/ Day 6; Contract Relax w/Agonist Contraction/Day 1; Contract Relax w/Agonist Contraction/Day 2; Control/Day 1; Control/ Day 2; Control/Day 3; Control/Day 4; Control/Day 5; Control/ Day 6; Control/Day 7

Table 15. Continued

Control/Day 1	40	80.38	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 4; Hold Relax/Day 5; Hold Relax/Day 6; Hold Relax. Day 7; Contract Relax w/Agonist Contraction/Day 2; Contract Relax w/Agonist Contraction/ Day 3; Contract Relax w/Agonist Contraction/Day 4; Contract R w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/Agonist Contraction/ Day 7
Control/Day 2	40	81.85	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 6; Hold Relax. Day 7; Contract Relax w/Agonist Contraction/Day 3; Contract Relax w/ Agonist Contraction/Day 4; Contract Relax w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/ Day 6; Contract Relax w/Agonist Contraction/Day 7
Control/Day 3	40	83.03	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 7; Contract Relax w/Agonist Contraction/Day 3; Contract Relax w/Agonist Contraction/ Day 4; Contract Relax w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/ Agonist Contraction/Day 7
Control/Day 4	40	83.20	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 7; Contract Relax w/Agonist Contraction/Day 3; Contract Relax w/Agonist Contraction/ Day 4; Contract Relax w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/ Agonist Contraction/Day 7
Control/Day 5	40	82.98	Contract Relax/Day 2; Contract Relax/Day 3; Contract Relax/ Day 4; Contract Relax/Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Hold Relax/Day 7; Contract Relax w/Agonist Contraction/Day 3; Contract Relax w/Agonist Contraction/ Day 4; Contract Relax w/Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/ Agonist Contraction/Day 7
Control/Day 7	40	84.40	Contract Relax/Day 3; Contract Relax/Day 4; Contract Relax/ Day 5; Contract Relax/Day 6; Contract Relax/Day 7; Contract Relax w/Agonist Contraction/Day 4; Contract Relax w/ Agonist Contraction/Day 5; Contract Relax w/Agonist Contraction/Day 6; Contract Relax w/Agonist Contraction/ Day 7

Table 16. Two-way interaction of range of motion for time across all 7 days

Group	Count	Mean	Different From
Pre/Day 1	34	78.47	Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/ Day 1; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5; Post/Day 6; Post/ Day 7; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7

Table 16. Continued

Pre/Day 2	34	81.14	Pre/Day 1; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/ Day 1; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/ Day 7; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
Pre/Day 3	33	82.69	Pre/Day 1; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
Pre/Day 4	33	84.05	Pre/Day 1;Pre/Day 2; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 2 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/ Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
Pre/Day 5	33	84.09	Pre/Day 1;Pre/Day 2; Pre/Day 6; Pre/Day 7; Post/Day 2; Post/Day 3; Post/ Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 2; 10 min post /Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
Pre/Day 6	32	86.00	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4 Pre/Day 5; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/ Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 6; 20 min post/Day 7
Pre/Day 7	33	86.40	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4 Pre/Day 5; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/ Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 6; 20 min post/Day 7
Post/Day 1	34	86.91	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4 Pre/Day 5; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/ ay 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 7
Post/Day 2		90.42	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/ Day 7; Post/Day 1;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post /Day 2; 10 min post/Day 3 10 min post/Day 5; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6
Post/Day 3	33	91.44	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/ Day 7; Post/Day 1;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/ Day 2; 10 min post/Day 3 10 min post/Day 4; 10 min post/Day 5; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
Post/Day 4	33	91.78	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/ Day 7; Post/Day 1;Post/Day 7; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3 10 min post/Day 4; 10 min post/Day 5; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/ Day 5; 20 min post/Day 6; 20 min post/Day 7
Post/Day 5	33	91.35	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/ Day 7; Post/Day 1;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post /Day 2; 10 min post/Day 3 10 min post/Day 4; 10 min post/Day 5; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7

Table 16. Continued

Post/Day 6	32	93.22	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1;Post/Day 2; Post/Day 3; Post/Day 5; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
Post/Day 7	33	93.99	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1;Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5; 10 min post/Day 1;10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6;10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
10 min post /Day 1	34	84.09	Pre/Day 1; Pre/Day 2; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6;10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
10 min post /Day 2	33	87.21	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 4; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 7
10 min post /Day 3	33	88.35	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5; Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4
10 min post /Day 4	33	89.09	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 3; Post/Day 4; Post/Day 5; Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5
10 min post /Day 5	33	88.76	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 3; Post/Day 4; Post/Day 5; Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5
10 min post /Day 6	32	90.69	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1;Post/Day 6; Post/Day 7;10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
10 min post /Day 7	33	91.02	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1;Post/Day 6; Post/Day 7;10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
20 min post /Day 1	34	82.15	Pre/Day 1; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7

Table 16. Continued

20 min post /Day 2	33	85.09	Pre/Day 1; Pre/Day 2; Pre/Day 3; Post/Day 1; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 2; 10 min post/Day 3; 10 min post/Day 4; 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 4; 20 min post/Day 5; 20 min post/Day 6; 20 min post/Day 7
20 min post /Day 3	33	85.89	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 3; 10 min post/Day 4 10 min post/Day 5; 10 min post/ Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 6; 20 min post/Day 7
20 min post /Day 4	33	86.73	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 3; 10 min post/Day 4 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/ Day 6
20 min post /Day 5	33	86.79	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Post/Day 2; Post/ Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 4 10 min post/Day 5; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 6; 20 min post/ Day 7
20 min post /Day 6	32	88.47	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/ Day 7; Post/Day 2; Post/Day 3; Post/Day 4; Post/Day 5;Post/Day 6; Post/ Day 7; 10 min post/Day 1; 10 min post/Day 6; 10 min post/Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5
20 min post /Day 7	33	88.99	Pre/Day 1; Pre/Day 2; Pre/Day 3; Pre/Day 4; Pre/Day 5; Pre/Day 6; Pre/Day 7; Post/Day 1; Post/Day 3; Post/Day 4; Post/Day 5; Post/Day 6; Post/Day 7; 10 min post/Day 1; 10 min post/Day 2; 10 min post/Day 6; 10 min post/ Day 7; 20 min post/Day 1; 20 min post/Day 2; 20 min post/Day 3; 20 min post/Day 4; 20 min post/Day 5

Table 17. Analysis of variance for range of motion, treatment, and stretch type

Source Term	DF	SS	MS	F-Ratio	*P*-level	Power
A: Tx	1	1213.41	1213.41	18.67	0.001*	0.99
B: Strch Type	3	7058.91	2325.97	36.21	0.001*	1.00
AB	3	8819.13	1939.71	45.24	0.001*	1.00
S	917	59590.80	64.98			
Total (Adjusted)	924	76233.53				
Total	925					

Table 18. Tukey-Kramer multiple-comparison for range of motion and treatment

Group	Count	Mean	Different From
PSWD	449	87.88	No PSWD
No PSWD	476	85.02	PSWD

Table 19. Tukey-Kramer multiple-comparison for range of motion and stretch type

Group	Count	Mean	Different From
Contract Relax	279	89.46	Hold Relax; Control
Hold Relax	173	84.90	Contract Relax; Contract Relax w/ Agonist Contraction; Control
Contract Relax w/ Agonist Contraction	193	88.57	Hold Relax; Control
Control	280	82.81	Contract Relax; Hold Relax; Contract Relax w/Agonist Contraction

Table 20. Tukey-Kramer multiple-comparison for range of motion and treatment and stretch type

Group	Count	Mean	Different From
PSWD/Contract Relax	112	90.64	PSWD/Contract Relax w/Agonist Contraction; PSWD/Control; No PSWD/Hold Relax; No PSWD/Control
PSWD/Hold Relax	61	91.25	PSWD/Contract Relax w/Agonist Contraction; PSWD/Control; No PSWD/Hold Relax; No PSWD/Control
PSWD/Contract Relax w/Agonist Contraction	136	86.22	PSWD/Contract Relax; PSWD/Hold Relax; No PSWD/I Relax; No PSWD/Contract Relax w/Agonist Contraction; No PSWD/Control
PSWD/Control	140	85.81	PSWD/Contract Relax; PSWD/Hold Relax; No PSWD/(Relax; No PSWD/Hold Relax; No PSWD/Contract Relax w/Agonist Contraction; No PSWD/Control
No PSWD/Contract Relax	167	88.67	PSWD/Control; No PSWD/Hold Relax; No PSWD/Contract Relax w/Agonist Contraction; No PSWD/Control
No PSWD/Hold Relax	112	81.45	PSWD/Contract Relax; PSWD/Hold Relax; PSWD/Contract Relax w/Agonist Contraction; PSWD/Control; No PSWD/Contract Relax; No PSWD/(Relax w/Agonist Contraction
No PSWD/Contract Relax w/Agonist Contraction	57	94.18	PSWD/Contract Relax w/Agonist Contraction; PSWD/Control; No PSWD/Contract Relax; No PSWD/I Relax; No PSWD/Control
No PSWD/Control	140	79.81	PSWD/Contract Relax; PSWD/Hold Relax; PSWD/Contract Relax w/Agonist Contraction; PSWD/Control; No PSWD/Hold Relax; No PSWD/Contract Relax w/Agonist Contraction

Table 21. Analysis of variance for range of motion and treatment

Source Term	DF	SS	MS	F-Ratio	*P*-level	Power
A: Tx	1	1893.16	1893.16	25.81	0.001*	0.99
B: Strch Type	3	7058.50	2352.83	32.08	0.001*	1.00
AB	3	11.75	3.92	0.05	0.98	0.06
S	917	67262.57	73.35			
Total (Adjusted)	924	76233.53				
Total	925					

Table 22. Tukey-Kramer multiple-comparison for range of motion and treatment

Group	Count	Mean	Different From
PSWD	449	87.88	No PSWD
No PSWD	476	85.02	PSWD

Table 23. Tukey-Kramer multiple-comparison for range of motion and time

Group	Count	Mean	Different From
Pre	232	82.65	Post; 10 min post; 20 min post
Post	231	90.19	Pre; 10 min post; 20 min post
10 min post	231	87.42	Pre; Post
20 min post	231	85.39	Pre; Post

Table 24. Tukey-Kramer multiple-comparison for range of motion for treatment and time

Group	Count	Mean	Different From
PSWD/Pre	113	84.27	PSWD/Post; PSWD/10 min post; No PSWD /Post
PSWD/Post	112	91.63	PSWD/Pre; PSWD/20 min post; No PSWD/ Pre; No PSWD/10 min post; No PSWD/20 min post
PSWD/10 min post	112	88.96	PSWD/Pre; No PSWD/Pre; No PSWD 20 min post
PSWD/20 min post	112	86.70	PSWD/Post; No PSWD/Pre
No PSWD/Pre	119	81.12	PSWD/Post; PSWD/10 min post; PSWD/ 20 min post; No PSWD/Post; No PSWD/10 min post
No PSWD/Post	119	88.85	PSWD/Pre; No PSWD/Pre; No PSWD 20 min post
No PSWD/10 min post	119	85.97	PSWD/Post; No PSWD/Pre
No PSWD/20 min post	119	84.15	PSWD/Post; PSWD/10 min post; No PSWD /post

Table 25. Analysis of variance for range of motion for treatment and stretch type

Source Term	DF	SS	MS	F-Ratio	*P*-level	Power
A: Tx	3	6433.99	2144.66	32.62	0.001*	1.00
B: Strch Type	3	7550.10	2516.70	38.28	0.001*	1.00
AB	9	1632.84	181.43	2.76	0.003*	0.96
S	909	59760.52	65.74			
Total (Adjusted)	924	76233.53				
Total	925					

Table 26. Tukey-Kramer multiple-comparison for range of motion and stretch type

Group	Count	Mean	Different From
Contract Relax	279	89.46	Hold Relax; Control
Hold Relax	173	84.80	Contract Relax; Contract w/Agonist Contraction; Control
Contract Relax w/ Agonist Contraction	193	88.57	Hold Relax; Control
Control	280	82.81	Contract Relax; Contract w/Agonist Contraction; Control

Table 27. Tukey-Kramer multiple-comparison for range of motion and time

Group	Count	Mean	Different From
Pre	232	82.65	Post; 10 min post; 20 min post
Post	231	80.19	Pre; 10 min post; 20 min post
10 min post	231	87.42	Pre; Post; 20 min post
20 min post	231	85.39	Pre; Post; 10 min post

Table 28. Tukey-Kramer multiple-comparison for range of motion and stretch type and time

Group	Count	Mean	Different From
Contract Relax/Pre	70	84.64	Contract Relax/Post; Contract Relax/10 min post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post
Contract Relax/Post	70	94.37	Contract Relax/Pre; Contract Relax/20 min post; Hold Relax/Pre; Hold Relax/10 mint post; Hold Relax/20 min post; Contract w/Agonist Contraction/Pre; Contract w/ Agonist Contraction/20 min post; Control/Pre; Control/ Post; Control/10 min post; Control/20 min post
Contract Relax/10 min post	70	90.87	Contract Relax/Pre; Hold Relax/Pre; Hold Relax/20 min post; Contract w/Agonist Contraction/Pre; Control/Pre; Control/Post; Control/10 min post; Control/20 min post
Contract Relax/20 min post	69	87.94	Contract Relax/Post; Hold Relax/Pre; Contract w/Agonist Contraction/Post; Control/Pre; Control/10 min post; Control/20 min post
Hold Relax/Pre	44	80.45	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/20 min post; Hold Relax/Post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post; Contract w/Agonist Contraction/20 min post
Hold Relax/Post	43	89.72	Hold Relax/Pre; Hold Relax/20 min post; Contract w/ Agonist Contraction/Pre; Control/Pre; Control/Post; Control/10 min post; Control/20 min post
Hold Relax/10 min post	43	86.05	Contract Relax/Post; Contract w/Agonist Contraction/Post
Hold Relax/20 min post	43	83.49	Contract Relax/Post; Contract Relax/10 min post; Hold Relax/Post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post
Contract w/Agonist Contraction/Pre	48	82.71	Contract Relax/Post; Contract Relax/10 min post; Hold Relax/Post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post
Contract w/Agonist Contraction/Post	48	94.04	Contract Relax/Pre; Contract Relax/20 min post; Hold Relax/Pre; Hold Relax/10 min post; Hold Relax/20 min post; Contract w/Agonist Contraction/Pre; Contract w/ Agonist Contraction/20 min post; Control/Pre; Control/ Post; Control/10 min post; Control/20 min post
Contract w/Agonist Contraction/10 min post	48	89.88	Contract Relax/Pre; Hold Relax/Pre; Hold Relax/20 min post; Contract w/Agonist Contraction/Pre; Control/Pre; Control/Post; Control/10 min post; Control/20 min post
Contract w/Agonist Contraction/20 min post	49	87.67	Contract Relax/Post; Hold Relax/Pre; Contract w/Agonist Contraction/Post; Control/Pre; Control/20 min post
Control/Pre	70	82.00	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/20 min post; Hold Relax/Post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post; Contract w/Agonist Contraction/20 min post
Control/Post	70	83.68	Contract Relax/Post; Contract Relax/10 min post; Hold Relax/Post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post
Control/10 min post	70	83.13	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/20 min post; Hold Relax/Post; Contract w/ Agonist Contraction/Post; Contract w/Agonist Contraction /10 min post
Control/20 min post	70	82.43	Contract Relax/Post; Contract Relax/10 min post; Contract Relax/20 min post; Hold Relax/Post; Contract w/Agonist Contraction/Post; Contract w/Agonist Contraction/10 min post; Contract w/Agonist Contraction/20 min post

Table 29. One-way Analysis of variance for range of motion and treatment

Source	DF	SS	MS	F-Ratio	P-level	Power
A:Tx	1	1921.36	1921.36	24.14	0.001*	0.99
S(A)	943	75057.02	79.59			
Total (Adjusted)	944	76978.38				
Total	945					

Table 30. Tukey-Kramer multiple-comparison for range of motion and treatment

Group	Count	Mean	Different From
PSWD	449	87.88	No PSWD
No PSWD	496	85.02	PSWD

Table 31. One-way Analysis of variance for range of motion and stretch type

Source Term	DF	SS	MS	F-Ratio	*P*-Level	Power
A: Strch Type	3	7527.96	2509.32	33.64	0.001*	1.00
S(A)	921	68705.58	74.60			
Total (Adjusted)	924	76233.53				
Total	925					

Table 32. Tukey-Kramer multiple-comparison for range of motion and stretch type

Group	Count	Mean	Different From
Contract Relax	279	89.46	Hold Relax/Control
Hold Relax	173	84.90	Contract Relax/Contract Relax w/Agonist Contraction
Contract Relax w/Agonist Contraction	193	88.57	Hold Relax/Control
Control	280	82.81	Contract Relax/Contract Relax w/Agonist Contraction

Table 33. One-way Analysis of variance for range of motion and time

Source	DF	SS	MS	F-Ratio	*P*-value	Power
A: Time	3	7065.60	2355.20	31.36	0.001*	1.00
S(A)	921	69167.93	75.10			
Total (Adjusted)	924	76233.53				
Total	925					

Table 34. Tukey-Kramer multiple-comparison for range of motion and time

Group	Count	Mean	Different From
Pre	232	82.65	Post, 10 min post, 20 min post
Post	231	90.19	Pre, 10 min post, 20 min post
10 min post	231	87.42	Pre, Post
20 min post	231	85.39	Pre, Post

Table 35. One-way Analysis of variance for range of motion and treatment

Source Term	DF	SS	MS	F-Ratio	*P*-Level	Power
A: Tx	1	1882.52	1882.52	23.37	0.001*	0.99
S(A)	923	74351.01	80.55			
Total (Adjusted)	924	76233.53				
Total	925					

Table 36. Tukey-Kramer multiple-comparison for range of motion and treatment

Group	Count	Mean	Different From
PSWD	449	87.88	No PSWD
No PSWD	476	85.02	PSWD

Table 37. One-way Analysis of variance for range of motion and day

Source Term	DF	SS	MS	F-Ratio	*P*-Level	Power
A: Day	6	4629.29	771.55	9.89	0.001*	0.99
S(A)	918	71604.24	78.00			
Total (Adjusted)	924	76233.53				
Total	925					

Table 38. Tukey-Kramer multiple-comparison for range of motion and day

Group	Count	Mean	Different From
Day 1	136	81.97	Day 3, 4, 5, 6, 7
Day 2	133	85.09	Day 6, 7
Day 3	132	86.33	Day 1
Day 4	132	86.92	Day 1
Day 5	132	86.92	Day 1
Day 6	128	88.88	Day 1/2
Day 7	132	88.97	Day 1/2

Table 39. Average power for each treatment and stretch type (Means ± SD; n = 8 subjects)

Stretch Type	PSWD	No PSWD
Contract Relax	1321.98 ± 260.82	1545.25 ± 382.16
Hold Relax	1165.51 ± 253.85	1504.35 ± 245.64
Contract Relax w/ Agonist Contraction	1619.18 ± 267.68	1533.84 ± 148.92
Control	1646.45 ± 146.01	1663.55 ± 332.42

Table 40. Average power for each treatment and day (Means ± SD; n = 8 subjects)

	PSWD	No PSWD
Day 1	1527.80 ± 304.06[A]	1518.21 ± 344.53[B,]
Day 2	1498.17 ± 261.79[C]	1574.35 ± 345.12[B, C]
Day 3	1519.29 ± 268.58[A]	1560.85 ± 317.82
Day 4	1529.81 ± 261.68[C]	1573.27 ± 337.86[B, C]
Day 5	1527.80 ± 250.36[C]	1587.5 ± 328.58[B, C]
Day 6	1539.74 ± 302.16[C]	1588.85 ± 331.02[B, C]
Day7	1564.94 ± 261.35[C]	1614.85 ± 311.49[B, C]

[A] Day 3 < 1
[B] Day 1 < 2, 4, 5, 6, 7
[C] PSWD < No PSWD

Table 41. Average power for each stretch type and day (Means ± SD; n = 8 subjects)

	Control Relax	Hold Relax	Contract Relax w/Agonist Contraction	Control
Day 1	1450.26 ± 403.50[A, C]	1378.98 ± 317.61[A]	1578.67 ± 240.07[A]	1614.40 ± 248.27[A, C]
Day 2	1470.47 ± 387.53[A]	1357.22 ± 315.45[A]	1566.37 ± 210.95[A]	1628.74 ± 226.42[A, C]
Day 3	1456.48 ± 346.92[A, C]	1331.38 ± 270.67[A]	1590.86 ± 221.67[A]	1641.26 ± 230.24[A, C]
Day 4	1472.23 ± 359.23[A, C]	1340.08 ± 315.08[A]	1604.32 ± 228.09[A]	1649.78 ± 224.24[A, C]
Day 5	1488.28 ± 339.34[A, C]	1367.99 ± 286.15[A]	1584.02 ± 239.24[A]	1652.53 ± 234.59[A, C]
Day 6	1493.63 ± 365.65[B,C]	1279.22 ± 300.22[B]	1581.66 ± 224.80[B]	1690.21 ± 238.67[B, C]
Day 7	1534.65 ± 347.01[B,C]	1380.07 ± 279.79[B]	1582.80 ± 244.66[B]	1691.80 ± 209.48[B, C]

[A] Hold Relax < Contract Relax < Contract Relax w/Agonist Contraction and Control
[B] Hold Relax < Contract Relax, Contract Relax w/Agonist Contraction, and Control
[C] Contract Relax < Control

Table 42. Average power for each day across time (Means ± SD; n = 8 subjects)

	Pre	Post	10 min post	20 min post
Day 1	1559.30 ± 361.61	1494.60 ± 300.50	1529.01 ± 304.67	1510.14 ± 322.17
Day 2	1567.95 ± 336.14	1529.81 ± 301.89	1514.27 ± 283.05	1529.63 ± 305.65
Day 3	1574.11 ± 301.71	1528.11 ± 295.83	1527.68 ± 283.67	1530.66 ± 296.58
Day 4	1585.35 ± 315.59	1539.99 ± 297.64	1532.43 ± 292.08	1548.70± 304.31
Day 5	1570.41 ± 308.16	1557.09 ± 275.09	1553.21 ± 294.01	1550.40 ± 296.88
Day 6	1594.29 ± 313.09	1552.10 ± 296.06	1539.74 ± 303.21	1569.54 ± 354.26
Day 7	1635.10 ± 292.85	1563.81 ± 294.63	1563.52 ± 281.51	1597.49 ± 279.88

APPENDIX C

Subject Information & Health History Questionnaire

Please answer the following questions to the best of your knowledge. Please place a check in the appropriate box. All information from this questionnaire will be kept confidential.

Subject ID number: _____

Please indicate the most appropriate answer to the following questions	Yes	No
1. Have you injured or had surgery on your leg in the past 6 months?		
2. Are you currently active in a sporting event?		
3. Are you currently taking any sport supplements?		
4. Have you ever had surgery requiring the permanent use of a metal implant?		
5. Do you know of or have any medical conditions that might aggravate you during the study?		
6. Do you know or have you ever had any heat related injuries?		

Should you become ill and/or incapable of finishing the study, alert the investigator (s) immediately.

APPENDIX D

Oklahoma State University Institutional Review Board

Date	Monday, February 08, 2010	Protocol Expires:	1/13/2011
IRB Application	ED09165		
Proposal Title:	Pulsed Short-wave Diathermy and its Influence on a Proprioceptive Neuromuscular Facilitation Stretching Protocol of the Hamstrings		
Reviewed and Processed as:	Expedited **Modification**		

Status Recommended by Reviewer(s) **Approved**

Principal Investigator(s) :

Ben Varilek	Blaine Long
180 Colvin Center	180 Colvin Recreation Center
Stillwater, OK 74078	Stillwater, OK 74078

The requested modification to this IRB protocol has been approved. Please note that the original expiration date of the protocol has not changed. The IRB office MUST be notified in writing when a project is complete. All approved projects are subject to monitoring by the IRB

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

Signature:

Sheila Kennison, Chair, OSU Institutional Review Board

Monday, February 08, 2010
Date

APPENDIX E

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
OKLAHOMA STATE UNIVERSITY

PROJECT TITLE: Pulsed short-wave diathermy and its influence on a proprioceptive neuromuscular facilitation stretching protocol of the hamstrings.

INVESTIGATORS: Benjamin P. Varilek ATC; Graduate Assistant, Health and Human Performance; Oklahoma State University; Stillwater, OK; 405-385-1681

PURPOSE:

This study is being conducted at Oklahoma State University. The purpose is to determine if deep heat application prior to 3 stretching protocols improve hamstring flexibility.

PROCEDURES:

Following your commitment to participate in this study, you will complete a health history questionnaire form in order to determine if you qualify for this study. If you qualify to participate in the study, you will sign this informed consent form and be randomly assigned to a treatment group. In order to determine which group you will be assigned to, you will take a piece of paper from a bowl with the numbers 1 or 2. You will also take a piece of paper from another bowl with the numbers 1, 2, 3, or 4 to determine which stretching technique you will receive. Depending on the number written on the piece of paper, you will receive a 20-minute heat treatment to your hamstrings or nothing (control).

On each day you will report to the Applied Musculoskeletal and Human Physiology Laboratory (Colvin Recreation Center; room 192) at the same time each day dressed in shorts and a t-shirt. You will then remove your shoes and socks and lie on your back on the padded table where a mark will be placed on the front of your knee on your dominant leg with a pen. Your opposite leg will then be stabilized to the table to prevent any additional motion. Baseline hamstring flexibility will then be measured by extending your knee. You will then be placed in the chair of a muscle strength machine where knee flexion measures will be recorded.

Following baseline measures you will return to the table and lie on your stomach where you will receive 1 of the 2 deep heat treatments to the back of your leg for 20 minutes. Following the treatment you will lay on your back and 1 of 4 stretch techniques (i.e. contract relax, hold relax, slow reversal hold, or control) will be administered. Immediately following, 10 minutes following, and 20 minutes following each stretch, additional hamstring flexibility and muscle strength measures will be recorded.

If you receive the hold-relax technique your leg will be stretched to the point of tightness and held for 10 seconds. You will then extend your hip towards the table while resistance the movement is applied. This movement will occur for 6 seconds.

If you receive the contract-relax technique your leg will be stretched again to the point of tightness and held for 10 seconds. You will then extend your hip against the examiner resistance through the full range of motion. Once completed you will be instructed to relax, and another stretch will occur for 30 seconds.

If you receive the third type of stretch, the hold-relax, your leg will be stretched again to the point of tightness and a passive prestretch will be applied to the subject and held for 10 seconds. You will then extend your hip with resistance to movement resulting in a muscle contraction held for 6 seconds.

The testing will occur over 7 consecutive days lasting for about an hour each day.

RISKS OF PARTICIPATION:

You may expect the following minor risks to occur. On some occasions individuals perceive the pulsed short-wave diathermy treatment as feeling too warm. To minimize this, towel/s will be applied between the diathermy unit and skin surface as needed.

BENEFITS OF PARTICIPATION:

You may gain an appreciation and understanding of how research is conducted. In addition, knowing that this data could provide useful evidence for understanding deep heating tissues effects on Range of Motion.

CONFIDENTIALITY:

All information about you will be kept confidential and will not be released. Questionnaires and record forms will have identification numbers, rather than names, on them. Research records will be stored securely and only researchers and individuals responsible for research oversight will have access to the records. This information will be saved as long as it is scientifically useful; typically, such information is kept for five years after publication of the results. Results from this study may be presented at professional meetings or in publications. You will not be identified individually; we will be looking at the group as a whole. It is possible that the consent process and data collection will be observed by research oversight staff responsible for safeguarding the rights and wellbeing of people who participate in research.

COMPENSATION

There is no penalty for refusal to participate, and that you are free to withdraw your consent and participation in this project at any time, without penalty. Participation in this research is voluntary and there is no compensation available for participation.

CONTACTS:

You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study: Benjamin P. Varilek, ATC, Colvin Recreation Center, Health and Human Performance, Oklahoma State University, Stillwater, OK 74078, (405)385-1681; ben.varilek@okstate.edu or Dr. Blaine Long, ATC, Colvin Recreation Center, Dept. of Education Oklahoma State University, Stillwater, OK 74078, (405)744-3670; blaine.long@okstate.edu. If you have questions about your rights as a research volunteer, you may contact Dr. Shelia Kennison, IRB Chair, 219 Cordell North, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu

PARTICIPANT RIGHTS:

Your participation in this research is voluntary. There is no penalty for refusal to participate, and that you are free to withdraw your consent and participation in this project at any time, without penalty. In case of injury or illness resulting from this research study, you are responsible for seeking medical treatment at the OSU Student Health Center or provider of your choice. Emergency medical treatment will be available by contacting 911. No funds have been set aside by Oklahoma State University to compensate you in the event of illness or injury.

CONSENT DOCUMENTATION:

I have been fully informed about the procedures listed here. I am aware of what I will be asked to do and the benefits of my participation. I also understand the following statements:

I affirm that I am 18 years of age or older.

I have read and fully understand this consent form. I sign it freely and voluntarily. A copy of this form will be given to me. I hereby give permission for my participation in the study.

_____ _____

Signature of Participant Date

I certify that I have personally explained this document before requesting that the participant sign it.

_____ _____

Signature of Researcher Date

APPENDIX F

Clinical Implications

Clinically, our results indicate that PSWD prior to PNF stretching should be incorporated when a clinician performs the hold relax or contract relax technique. When combined, these techniques had the greater hip flexion ROM. In contrast, if the objective is to increase power, clinicians should avoid using PSWD and PNF stretching for it may have a negative effect.

APPENDIX G

Recommendations for Future Research

- Determine if muscular power measures in the treatment alone alters our results.
- Determine if expanding the sample size would reveal a difference between PNF stretch types on ROM gains or average power production.
- Determine if neuromuscular changes as measured with electromyography has an effect on motor recruitment during the treatment or PNF stretch type.
- Determine if intratissue temperature changes associated with the PSWD treatment and PNF stretch type influences the recommended stretching window.

VITA

Benjamin Patrick Varilek

Candidate for the Degree of

Master of Science

Thesis: PULSED SHORT-WAVE PSWD AND ITS INFLUENCE ON A PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION STRETCHING PROTOCOL OF THE HAMSTRINGS

Major Field: Applied Exercise Science

Biographical:

Education:

Bachelor of Science	University of Nebraska – Kearney Major: Exercise Science Comprehensive Area of Emphasis: Athletic Training	May 9, 2008

Completed the requirements for the Master of Science or Arts in Applied Exercise Science at Oklahoma State University, Stillwater, Oklahoma in May, 2010.

Experience:

University of Nebraska – Kearney	Undergraduate Athletic Training Student Athletic Training Students Association Vice-President Treasurer	 2007-2008 2006-2007
Oklahoma State University	Graduate Assistantship, Department of Health and Human Performance	
Teaching Responsibilities	HHP 2602: First Aid & CPR HHP 2654: Applied Anat. Lab. HHP 2664: Mech. & Manage. of Musculo. Path. HHP 2844: Assess. of Low. Ext. Injury	

Professional Memberships:
National Athletic Trainers' Association

Name: Benjamin Patrick Varilek Date of Degree: May2010
Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: PULSED SHORT-WAVE PSWD AND ITS INFLUENCE ON A PROPRIOCEPTIVE NEUROMUSCULAR FACILITATION STRETCHING PROTOCOL OF THE HAMSTRINGS

Pages in Study: 67 Candidate for the Degree of Master of Science

Major Field: Applied Exercise Science

Scope and Method of Study: The purpose of this study was to examine the effects of a 20 minute pulsed short-wave PSWD (PSWD) treatment on a proprioceptive neuromuscular facilitation (PNF) stretching protocol of the hamstrings. For this human subjects approved study, 35 healthy subjects with no history of lower extremity surgery or injury in the 6 months prior to the study volunteered. Thirty-four subjects (male: n = 19, age = 22.89 ± 3.13 yrs, ht = 172.89 ± 6.30cm, mass = 77.84 ± 9.35 kg; female: n = 16, age = 20.44 ± 2.28 yrs, ht = 163.06 ± 6.06 cm, mass = 70.50 ± 10.94 kg) completed all requirements of the study. Subjects received baseline range of motion (ROM) and average power production taken prior to a 20 minute PSWD or No PSWD treatment. Immediately post treatment, a contract relax, hold relax, contract relax w/ agonist contraction, or control (nothing) PNF stretch was performed. Immediately post, 10 minutes post, and 20 minutes post stretching.

Findings and Conclusions: Subjects receiving contract relax and contract relax w/ Pulsed short wave PSWD produced greater ROM in the contract relax and contract relax w/ agonist contraction groups ($P < .001$). Those who received PSWD prior to contract relax and hold relax had greatest hip flexion ROM ($P = .001$). Those receiving PSWD on Days 2 and 5 had greater hip flexion ROM than those not receiving PSWD ($P = .03$). Range of motion increased for those receiving PNF stretching ($P < .05$). Subjects receiving contract relax and contract relax w/ agonist contraction increased ROM ($P < .001$). There was no difference between treatment and stretch type for muscle power ($P = .61$). Those in the hold relax group however, had less muscular power than those in the contract relax, contract relax w/ agonist contraction, and control groups ($P < .05$).

ADVISER'S APPROVAL: Blaine C. Long