The global effects of differing durations of static stretching within a full warm-up protocol on subsequent voluntary performance and evoked contractile properties.

by ©

Jonathan Christopher Reid

A thesis submitted to

the School of Graduate Studies

In partial fulfillment of the requirements for the degree of

Master of Kinesiology School of Human Kinetics and Recreation

Memorial University of Newfoundland

St. John's, Newfoundland and Labrador

ABSTRACT

The evidence for performance decrements with prolonged static stretching (SS)(>60s per muscle group) has led to a paradigm shift in optimal stretching routines within a full warm-up protocol. Many athletic teams and individuals have now incorporated dynamic stretching (DS) and dynamic activity (DA) rather than SS into their pre-exercise warm-up routines. However, much of the previous research examining SS did not incorporate all three components of a full warm-up protocol (aerobic, SS and DS/DA activity). Based on previous literature, the objective of the present study was to compare differing durations of SS (30, 60, and 120 seconds per muscle group or a control condition with no SS) within in a full warm-up protocol on various testing measures. Sixteen male participants (Sixteen males; 27.6 ± 2.15 years, 187.1 ± 15.3 lb. and 181.9 ± cm) with an athletic background and at least 2 years of strength and endurance training experience completed four conditions, each condition included a prior submaximal 5-minute aerobic warm-up on a cycle ergometer, one of the four SS interventions (0, 30, 60 or 120s per muscle group) and a subsequent DS/DA component. Results of the present study serve as evidence that prolonged durations of SS (SS 120s) per muscle group, even with the inclusion of a DS/DA component can impair subsequent performance in vertical jump height, force production and rate of force production, evoked contractile properties and potentiated twitch forces, and the interpolated twitch technique. Results also show that ROM continues to increase immediately following each of the three components within the warm-up (aerobic, SS and DS/DA) in all conditions.

ACKNOWLEDGMENTS

I would like to express my gratitude to my family for the continuing support throughout my life. My mother Ann-Marie Lannon, father Robin Reid and brother Jeffrey Reid have always been there for me and I am very lucky to have them.

Next I have to thank Keila Brittany Hicks. You are a true inspiration and I cannot thank you enough for everything you have done for me.

To my supervisor Dr. David Behm, thank you for offering me such a great opportunity to pursue my Master’s degree at Memorial University. I am grateful for the incredible learning experience and knowledge I have gained from you. You are an inspiration and have truly impacted my life and future.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

1-RM	One Repetition Maximum
Anova	Analysis of Variance
CM	Centimeters
DA	Dynamic Activity
DS	Dynamic Stretching
EMD	Electromechanical Delay
EMG	Electromyography
ES	Effect Size
F100	Force Produced in the First 100 milliseconds of an MVC
GTO	Golgi Tendon Organs
Hz	Hertz
ICC	Intraclass Correlation Coefficient
iEMG	Integrated EMG
ITT	Interpolated Twitch Technique
Kg	Kilogram
ms	Millisecond
mV	Millivolt
M-WAVE	Peak Muscle Action Potential
M-WAVE DURATION	Duration of Peak Muscle Action Potential
MTU	Musculotendinous Unit
MVC	Maximum Voluntary Contractions
PNF	Proprioceptive Neuromuscular Facilitation
POD	Point of discomfort
PT	Twitch Torque Amplitude
ROM	Range of Motion
s	Seconds
SD	Standard Deviation
SS	Static Stretching
SSC	Stretch Shortening Cycle
TPT	Time to Peak Twitch Torque
VA%	Voluntary Activation

Chapter 1: Review of Literature

1.1 Introduction

Static stretching (SS) has been considered an essential component of a warm-up for decades, and to this day it is used in a wide variety of activities and sports (Young & Behm, 2002; Ebben, 2001 & Simenz, 2005). In the athletic community, various types of warm-up protocols, depending on the athlete and sport, are specifically designed and implemented prior to an event. According to Young & Behm (2002) a warm-up should have three components: low intensity aerobic activity, stretching the involved muscles, and rehearsal of the sport or activity specific skill.

Recently, a growing body of evidence has reported negative effects of prolonged SS on subsequent maximal power production and performance, (Behm et al., 2001; Costa et al., 2009e; Cramer et al., 2007a; Fowles et al., 2000), countermovement jump (Bradley et al., 2007; Fletcher & Monte-Colombo, 2010; Curry et al., 2009 and Wallman et al., 2005) and sprint time (Fletcher & Jones, 2004; Kistler et al., 2010; Sim et al., 2009; Winchester et al., 2008). SS reviews (Behm & Chaouachi, 2011; Kay & Blazevich, 2012) show SS induced impairments in performance incurring an average decrease of 5-7.5%. A 5% or greater decrease in maximal ability may not seem substantial, but to an elite athlete, 5% could be the difference between a world record or professional career.

There is a preponderance of evidence indicating that prolonged SS (60 seconds and above) impairs subsequent performance (Behm et al., 2016, Behm & Chaouachi, 2011; Kay & Blazevich, 2012), but most of these studies have stretching performed in isolation without the benefits of a full warm-up. Worrell et al. (1994) was one of the first studies to show SS enhanced performance in hamstrings concentric and eccentric torque following four hamstring SS of 20 seconds per repetition. However, a majority of research to follow tended to show a decrease in performance following a session of SS. Kokkonen et al. (1998) showed a 7-8% decrease in knee flexion and extension following a SS intervention. Following Kokkonen's work, Fowles et al. (2000) demonstrated a 28% decrease in plantar flexor maximum force following 13 plantar flexor SS of 135 s per stretch. Additionally, Fowles showed that SS-induced impairments were maintained for 60-minutes post SS with a continued 9% force impairment. Furthermore, Behm et al. (2001) and Power et al. (2004) demonstrated impairments in performance following SS of the quadriceps, hamstrings and plantar flexors. Each SS was repeated 3 times and held for 45 seconds per muscle group. Decrements in performance were observed in torque (9.5%) of the quadriceps. Force remained significantly decreased (10.4%) for 120 minutes following the SS intervention. Results from Power et al., (2004) exhibited impairments from SS on subsequent performance immediately and up to 120-minutes following a SS intervention. Therefore, the perception regarding SS within a warm-up protocol has changed drastically. However there is evidence demonstrating SS can increase or have no effect on sprint time (Beckett et al., 2009), force (Alpkaya & Kocceja, 2007; Beedle et al., 2008), countermovement jump height (Behm et al., 2011; Burkett et al., 2005; Chaoachi et al., 2010).

The majority of researchers, coaches, trainers athletes now include dynamic stretching (DS) into experimental designs and warm up protocols, respectively. DS is more accepted as a stretching component for the muscles during the warm-up and seems to provide an efficient way for athletes to prepare physiologically for events.

DS involves controlled movement through the active range of motion (ROM) for each joint and can assist an athlete's preparation by using more sport specific movements (Fletcher, 2010). Dynamic warm-up techniques seem to be replacing other stretching techniques in warm-up protocols, but research provides conflicting evidence showing that it can either increase performance or have no detrimental effect on vertical jump height (Jaggers et al., 2008; Unick et al., 2005; Samuel et al., 2008 Kirmizigil et al., 2014; Hough et al., 2009; Haghshenas et al., 2014, Curry et al., 2009; Duncan & Woodfield, 2006), balance (Belkhiria Truki et al., 2014), concentric and eccentric torque output of quadriceps and hamstrings (Sekir et al., 2009), and sprint time (Amiri- Khorasani et al., 2011; Fletcher & Annes, 2007; Gelen, 2010). The increase in performance following DS arises from the specific movements that directly simulate movement patterns required in a sport of interest (Yamaguchi & Ishii, 2005). Warm-ups should prepare the body, not cause performance decrements. Therefore, it is important that the warm-up is executed properly and creates positive physiological changes in preparation for the sport.

Several original (Kay & Blazevich, 2012; Knudson & Noffal, 2005; Robbins & Scheuermann, 2008; Siatras et al., 2008) and review (Behm et al., 2016, Behm & Chaouachi, 2011; Kay & Blazevich, 2012) articles propose that SS of 60 seconds or more per muscle group will likely result in significant performance impairments whereas SS of shorter durations will in most cases have less of an effect (Behm & Chaouachi, 2011, Kay & Blazevich, 2012, Behm et al., 2016). Studies using prolonged SS of 60 or more seconds per muscle found impairments on average ranging from -1.2 to -8.5% in measures such as sprint running velocity (Fletcher & Jones, 2004), jump height (Hough et al., 2009) and knee extensor maximum voluntary contractions (MVC) (Siatras et al., 2008). Interestingly, not all SS of 60 seconds or longer per muscle group reported a decrease in subsequent performance. Little and Williams (2006) showed a increase in sprint time whereas Murphy et al., (2010) demonstrated a increase in jump height and O'Conner et al., (2006) found an increase in peak cycling power. Thus, there seems to be no clear evidence of impairment with short duration SS on power and speed based activities. According to Behm et al. (2016), less than 60 seconds of SS is recommended within a full warm-up protocol to avoid impairments in subsequent performance. However, there are only a small number of studies that use a full warm-up protocol (Beckett et al., 2009; Chaouachi et al., 2010; Kistler et al., 2010; Sekir et al., 2009 & Fortier et al., 2013). Therefore, there is a need to test the Behm et al., (2016) hypothesis with short durations (less than 60 seconds) and longer durations (60 plus seconds) of SS per muscle group within a full warm-up protocol.

The remainder of this literature review will be divided into the six following sections: stretch reflex mechanisms, static stretching and power, static stretching duration, static stretching intensity, dynamic stretching and full warm-up protocols. The purpose of this review is to provide insight regarding how athletes can execute proper warm-up routines, with or without SS and the importance of DS and sports specific movements within warm-up protocols. If static stretching is included, to what duration and intensity should one incorporate it into a warm up routine without any decrease in performance? Elite athletes cannot jeopardize performance by losing the ability to exert and perform maximally. Therefore, investigating differing SS durations within a full warm-up protocol should lead to a better understanding for the athlete and coach in regard to warm-up design and implementation dependent on the sport and athlete.

1.2 Stretch Reflex Mechanisms

Stretching involves the application of internal or external forces intended to bring muscles through a ROM at the joint of interest, increasing overall elongation of the musculotendinous unit (MTU) (Brooks, 1986; Behm & Chaouachi, 2011; Taylor et. al., 1990). The MTU consists of muscle cells, connective tissue, nerve cells, and blood vessels that help maintain shape, strength, blood flow, and activation of all muscles in the body (Taylor et al., 1990; Ce et al., 2008). The muscle cells are shaped in a cylindrical fashion and are arranged in parallel from one end of the muscle to the other. Each muscle fibre is held in place by strong connective tissue that connects the muscle to the joint while the surrounding connective tissue strengthens and grows with the muscle but at a slower rate (Houglum et al., 2001). Within each muscle there are proprioceptors to help protect muscles from injury as they are put through a ROM. Proprioceptors, such as Golgi tendon organs (GTO), can sense the tension and pressure that is exerted in the muscle-tendon at a given time. If a GTO is activated it can generate an inhibitory response in an attempt to prevent damage, tearing, or rupturing of the MTU (Houglum et al., 2001). GTOs consist of many nerve endings that are implanted within the tendon junctions of each muscle fibre. When tension is increased, the GTOs are activated, causing an inhibition reflex and relaxation of the muscle to prevent injury (Houglum et al., 2001).

Another proprioceptive organ found in the muscle is the muscle spindle located within the body of the muscle. Muscle spindles determine the rate and length at which a muscle is stretched, acting as a safety mechanism that protects the muscle undergoing an eccentric lengthening contraction and passive lengthening (Guyton & Hall, 1996).

Muscle spindles consist of two important fibers: the nuclear bag and nuclear chain fibers. These two fibers react to the rate and extent of change (Guyton & Hall, 1996). The nuclear chain fibers are smaller and the nuclei are spread throughout the spindle in a chain-like fashion. Nuclear chain fibers are static and responsible for sending afferent and receiving efferent feedback regarding the extent of change in the length of each individual muscle spindle (Guyton & Hall, 1996). The nuclear bag fibers are clustered in the middle of the spindle and each bag fiber has sensory and motor innervation. Stretching of the nuclear bag is detected by group Ia and II nerve fibers; Ia fibers come from the annulospiral endings of the middle region of the bag and group II originate from secondary flower spray endings (Guyton & Hall, 1996). When the muscle is stretched then the nuclear bag and chain will stimulate the Ia and II afferent fiber. This stimulation sends an impulse to the spinal cord where it will synapse on the alpha motor neurons causing contraction and shortening of the muscle, also known as the myotatic reflex or stretch reflex (Houglum, 2001). Spindles are surrounded by sensory nerves that will generate an impulse if the rate and length of the muscle fiber is altered too quickly or exceed the muscles normal ROM. Upon activation of a muscle spindle, a reflex response will be generated that will contract the agonist muscle while creating an inhibitory response to the antagonist muscle (Houglum, 2001).

1.3 Static stretching and performance

SS is a common method of warming up prior to an athletic event. SS is found to increase the MTU compliance, flexibility, and ROM by affecting how the body reacts to enhanced mechanical lengthening of the muscle (Nakamura et al., 2011). With a majority of sports requiring power, explosiveness and speed to excel at a high level, the slightest decrease in performance can significantly affect an athlete's overall performance. Therefore, it is crucial that an athlete does not jeopardize maximal performance with prolonged SS during a warm up routine. One of the mechanisms underlying SS-induced impairments has been attributed to increased compliance (Behm &Young, 2002; Fletcher, 2004) within the MTU subsequently following a bout of SS. Increased compliance can occur within the MTU following a session of longer duration (i.e., 60 to 90 seconds or more per muscle group) of SS (Behm & Young, 2002). Increased muscular compliance can cause performance decrements because of the slower electromechanical delay (EMD) and overall time for the concentric and eccentric transition phase to take place. (Behm & Chaouachi, 2011). The slower EMD will create a longer time to endure the lengthened MTU, thus delaying the time it takes before the muscle moves upon activation. An increased EMD reduces the speed and rate of force development within an activated muscle (Behm & Chaouachi, 2011). When a muscle is overstretched the ideal length for optimal performance may also be altered. When elongating the MTU, altering the force-length (or length-tension) relationship via SS, the muscle can cause a drop in overall force production that can last 1-2 hours post stretching (Power et al., 2004). While many exercise professionals, elite athletes, and coaches continue to implement SS into the warm-up routines, many researchers have found negative effects (Behm, Bambury, Cahill, & Power, 2004; Behm, Button, & Butt, 2001; Boyle, 2004; Cornwell et al., 2001; Fletcher & Annes, 2007; Fletcher & Jones, 2004; Fowles et al., 2000; Kokkonen et al., 1998; McMillian, Moore, Hatler, & Taylor, 2006; Ogura et al., 2007; Young & Behm, 2003).

We know that SS may result in potential decrements in strength, power, and speed. Moss (2002) used elite soccer players to determine if SS prior to the Illinois Agility test would impact performance. Moss had participants perform SS, DS, or no stretching, immediately after running one mile in ten minutes and then perform agility testing. Out of the three conditions there were no evident decreases in neural and muscular performance, inhibition of power, strength, or speed, suggesting that not all SS leads to a drop in performance.

Many explosive and power movements are facilitated by the stretch shortening cycle and transition phase. If both phases are slower via SS, then stored energy from the eccentric loading portion will be lost and dissipated as heat instead of being transferred to the concentric phase (Potach, 2004). A decrease in MTU stiffness can cause an increased time for force development of muscle activation via the lengthened tendon, thus resulting in a less effective transfer of force from muscle to lever (Wilson et al., 1991). Many studies have examined the effects of SS on power and speed production. Popular test protocols include sprints, agility, vertical jump, contact time, plus other movements that require an efficient EMD, stretch-shortening cycle (SSC) and transition phase. The aforementioned mechanisms can play a significant role in subsequent performance impairments.

When investigating the effects of warm-up protocols on subsequent performance, it is important to include DS and dynamic movements within the warm-up design. Furthermore, Fletcher (2008) analyzed the effects of SS and DS warm-up protocols on 20-m sprint performance. When SS was incorporated into the warm-up protocol there was an increased 20m sprint time when compared to DS sprint times. This deficit in sprint time exhibited following SS was attributed to the increased compliance in the MTU (Fletcher, 2008). When examining the groups that performed the DS warm-up protocol, the post-DS sprint time was significantly faster. The decreased sprint times following DS was attributed to the similar movement patterns involved in the warm-up protocol thus promoting increased coordination and neural drive (Fletcher, 2008). In accordance with Fletcher (2008), McMillan et al. (2006) reported increased performance in the T shuttle run, medicine ball throw and 5-step jump following DS and control conditions versus SS. The previously mentioned studies show that the adverse effect of SS is prevalent in sports and test measures that require excessive power and explosiveness to perform at top levels. Results from previously completed research also suggest that DS may be more appropriate in preparing an athlete's body during a warm-up routine.

There is SS research that exhibits no impairment in performance. For example, SS did not impair the velocity of sprint speed and muscular power of professional soccer players (Little & Williams, 2004). Interestingly, despite SS not inhibiting submaximal performance, the DS was more optimal for the 10m sprint, 20m sprint and agility times when compared to the other conditions (Little & Williams, 2004).

Contrary results were found by Bacurau et al. (2009) who found 3 sets of 6 repetitions of SS held for 30 seconds to the POD decreased leg press 1 repetition maximum (1RM) by 19.1%. Five different warm-ups were in the study by Young and Behm (2003) with increased durations of SS producing the lowest values for explosive force production in jump heights. Herda et al. (2008 & 2010) used 9 repetitions of 135 seconds of SS in both experiments, with all stretching brought to the POD. In the 2008 and 2010 Herda studies, plantar flexor torque decreased 10.8% and 11.5% respectively following a bout of SS. The aforementioned studies agree with the hypothesis that SS does generate performance impairments, especially in movements that require speed, explosiveness, power, and agility. There are many factors that to consider when using SS: intensity, duration, and the POD of the stretch. Therefore, it is crucial to investigate how to incorporate SS into warm-up routines without potential deficits in performance.

Another way to analyze SS and performance is to incorporate SS within power, strength and conditioning training programs. Hunter & Marshall (2002) assessed the effects of power and flexibility training on the countermovement and drop jump techniques. Subjects were to perform 4 different conditions; power training to increase jump height, SS to increase flexibility, power and stretch training, and a control group. Training for the study consisted of 10 weeks where testing was done immediately after the final training sessions of the tenth week. Of all 4 conditions, the control group was the only group to not increase countermovement jump height. The power and SS and the power group were the only groups to increase drop jump height. Results show that jump height can increase when incorporating SS training in conjunction with various power-training exercises.

When SS is incorporated into training programs of longer durations, research tends to show an increase or no effect in subsequent performance (Handel et al., 1997; Hunter & Marshall, 2002; Gajdosik et al., 2005). Thus, SS training protocols may contradict acute SS studies that typically show impairments in successive performance (Behm, Bambury, Cahill, & Power, 2004; Behm, Button, & Butt, 2001). When SS was incorporated into a training program 3 times per week for 8 weeks there was an increase in maximal dorsiflexion ROM, passive resistive forces and the absorbed and retained passive- elastic energy (Gajdosik et al., 2005). Studies by Handel et al. (1997), Hunter and Marshall (2002) and Gajdosik et al. (2005) show that SS may not be as harmful in subsequent performance as it may be perceived, especially when SS is practiced on a regular basis. Additional research must be conducted using prolonged SS programs to observe changes between SS trained vs. untrained participants and the potential increase in performance when SS is implemented into a long- term program. If training can reduce the SS effects while allowing an increase in ROM, force and power then it will change the current perception regarding SS that typically discourages SS prior to an athletic event.

1.4 Static stretching and power

Depending on the warm-up approach, one involving SS between 60- 90 seconds may cause decreased risk of injury, decrease performance, as well as cause neurological, muscle, and mental fatigue (Behm et al., 2011). Another reason for SS-induced performance decrements is the reduction in neuromuscular drive affecting motor unit activation. Much of the research conducted on acute changes of stretching show that all stretching types increase the ROM of the MTU, but SS and PNF stretching shows the greatest negative effect when examining maximum power, peak performance, peak torque, and other measures related to performance (Behm et al., 2016; Cramer et al., 2004 & 2005, Padadopoulos, 2005). Considering that SS may inhibit performance, it is important to set a concrete guideline in which athletes can follow, depending on the sport, to ensure maximal torque and power production is not limited following an acute bout of SS. Padadopoulos et al. (2005) showed torque generated by the knee flexors and extensors were significantly lower in the SS group with no effect on the DS condition. Cramer et al. (2005) required participants to perform 4 sets of 4 SS, each exercise was held for 30 seconds and the muscle of interest was brought past the POD. It was found that SS caused a decrease of 2.7% in leg isokinetic peak torque. Please note that overall, each muscle was stretched for 120 seconds, which may be unrealistic in the general or athletic population regarding the duration one would hold a SS. To further investigate SS and torque, a study was conducted that required participants to perform 4 sets of 4 SS exercises x 30 seconds at a 60 degree and 180 degree angle. Results of the study by Cramer et al. (2005) showed a decrease in leg isokinetic peak torque of 1.1% and 6.5%, respectively. Franco et al. (2008) used 1 repetition x 20 seconds, 1 repetition x 40 seconds, and 1 PNF technique all to the POD, resulting in a total decrease in muscle endurance by 7.8%, 19.2%, and 24.5%, respectively.

The aforementioned evidence indicates that SS of even 20 seconds may cause a deficit in performance, especially if the muscle is brought to or past a POD. This brings forth the question: is the high intensity or duration of stretching or a combination of time and intensity of SS that lead to subsequent performance impairments? One problem is that most athletes, especially at advanced levels, cannot risk decreasing performance following a warm-up routine. One area of contention for SS is the duration in which a muscle should be stretched.

1.5 Static stretching duration

A factor contributing to potential decrements following SS may be the overall stretch duration. Young et al. (2006) and Knudson & Noffal. (2005) were among the first researchers to examine the volume and intensity effects that may come immediately following SS. Young et al. (2006) found that 1 minute of SS generated significantly less jumping impairments than 2 or 4 minutes, thus the greater duration of SS resulted in lower vertical jump heights. Past research indicates that if the total duration of SS exceeds 60-90 seconds (e.g., 3 stretches of 30 seconds) that there is likelihood for impairments in subsequent performance (Kay & Blazevich, 2012; Behm et al., 2016, Behm & Chaouachi, 2011, Behm & Young, 2002). Often the duration of SS utilized in experimental protocols doesn't correlate to how athletes would stretch during a practical pre-event warm-up. The average athlete will hold a SS for roughly 12-18 seconds (Ebben et al., 2001, 2004, 2005; Simenz, 2005) depending on the sport and ROM needs of the individual. Most studies use a range of 30-90 seconds of static and dynamic movement, whereas some studies have used stretching for a total of 20-60 minutes (Behm et al., 2001; Fowles et al., 2000). Many studies that require moderate to longer durations of SS have reported impairments in areas such as movement speed, time, balance, power, and velocity (Behm et al., 2004). Also, important to note is that impairments from SS are not just immediate – they can last up to 2 hours post-stretching (Power et al., 2004) and even up to 24 hours post-intervention (Haddad, 2014). Fowles et al. (2000) reported SS induced impairments up to an hour after the protocol, but the amount of SS surpassed the average length most athletes would stretch. Where Young et al. (2006) also analyzed performance decrements following SS, results from the experiment found that 1 minute of SS led to a drop in performance lasting an hour after the warm-up. Nonetheless, various studies found no drop in performance after a bout of SS. For example, a study was conducted to test the strength of a 1RM post-SS; participants were to perform 3 repetitions of 15 seconds of SS per muscle group. Results demonstrated no decrease in participant's strength for the bench press and leg press, indicating that SS can also lead to no change or an increase in subsequent performance (Beedle et al., 2007). Results from Beedle et al. (2007) contradict results of previously mentioned research conducted on the effects of SS on maximum performance. Bradley et al. (2007) protocol required brief intervals of SS with the main goal of investigating potential performance impairments following various warm-up protocols. Results from Bradley et al. (2007) found no reduction in performance following the SS protocol that required 4 repetitions of 5 stretches lasting 5 seconds per stretch. Results showed no influence on vertical jump height performance before and after stretching, suggesting the SSC, transition phase, EMD, power, strength, and other important factors were not affected by SS.

SS impairments can also be dependent on the test condition included within experimental designs. For example, Jaggers et al. (2008) found no impairments in participant's jump height performance, but did see an increase of 3.8% and 4.1% in force and power when using 5 stretches held for 2 seconds for each of the 15 repetitions. To test lower repetitions and shorter durations of SS, Samuel et al. (2008) used 2 repetitions of 30 seconds of ballistic and SS with muscles being stretched past the POD. Results from Samuel et al. (2008) found no change in the vertical jump height or torque immediately following a bout of SS. To analyze SS past the recommended 60-90 second range, Sayers et al. (2008) used 3 exercises with either 30 or 90 seconds durations of SS, results indicated an increase in participants sprint time (slower) by 2.1% with the 90 second versus 30 second SS condition. The duration of the SS seems to be an important indicator when determining whether or not performance deficits will be present following SS: therefore, Nelson et al. (2005b) used moderately longer SS durations to see the influence on sprint times. Nelson et al. (2005b) required participants to perform 4 repetitions of 30 seconds per each of the 4 SS exercises, each SS required participants to reach a ROM that was just past the POD. Results showed an overall decrease in the 20-meter sprint time of 2% following the SS condition. Supporting Nelson et al. (2005) findings, Siatras et al. (2003) used 60 seconds of SS and found that gymnast's sprint time was decreased by 3.8%. As Siatras et al. (2003) duration of 60 seconds sits at the duration threshold recommended by Behm and Chaouachi (2011), Kay and Blazevich (2012) and Behm et al. (2016) their results contribute to increased confusion and lack of concrete evidence in current research regarding SS and warm-up durations, and how coaches and athletes should properly incorporate, reduce, or eliminate static stretching prior to an event.

Furthermore, agility and explosiveness are capacities that can be jeopardized from bouts of SS. Agility testing was used by Mohammadtaghi et al. (2010) where subjects were required to perform 1 repetition of 30 seconds of SS. Results found a decrease of 5.1% on the Illinois agility test. This percentage shows impairments are present at even 30 seconds of SS. Gelen (2010) required participants to perform 5 SS, consisting of 1 repetition held for 20 seconds and 1 repetition of 30 seconds. The outcome from Gelen (2010) displayed a decreased sprint time and slalom dribbling of a soccer ball by 8.5% following the SS condition. Vetter (2007) used 60 seconds of SS and found a decreased jump height, but seen no decrease in post-SS sprint time. These findings oppose those found in studies by Chaouachi (2010), Mohammadtaghi (2010), and Siatras (2003), which found a decrease in sprint or agility with similar SS durations.

The role of the SSC and length tension relationship is crucial to jump height and if impaired by static stretching will result in performance decrements. Behm et al. (2006) found no effect of SS on jump height. In this study, participants were asked to perform 3 repetitions of 30 seconds per SS exercise. All of the SS were also brought past the POD. Behm et al. (2006) found no effect on jump height performance following SS, but did see an increased contact time by 5.4%. The increased contact time could be from the increased elongation of the MTU following a bout of SS. Increased MTU length can also create slack within the MTU, more slack is seen with prolonged and higher intensity SS. The increased slack of the MTU will also delay movement time and increase the transition and take-off phase. Gonzalez Rave et al. (2009) required participants to perform 3 SS with each of the 3 repetitions lasting 15 seconds and taken past the POD. The countermovement and squat jump were used as test measures. The outcome from Gonazalez Rave et al. (2009) showed no negative impact on jump height, with an increase of 3.1% for the countermovement and an increase of 11% for the squat jump. Therefore, using a SS of 45 seconds, which is within the recommended range of 30 to 60 seconds, can also generate increased performance, not only performance decrements.

1.6 Static stretching intensity

Bringing a muscle past or to the POD is common for an athlete during SS, but is it necessary to stretch to maximal length and intensity? Past research supports the fact that when a muscle is stretched to or past the POD that performance impairments are evident for force (Behm et al., 2001, 2004, 2006; Fowles et al.,2000; Nelson et al. 2001a; Power et al., 2004; Young & Behm 2003), jump height, increased contact, drop jump time (Cornwall et al., 2002; Young & Elliot 2001; Young & Behm 2003; Behm et al., 2006), decreased muscle activation, reaction time, balance, and speed with respect to time (Behm et al., 2001; Power et al., 2004; Behm et al., 2004). The previously mentioned studies required participants to stretch targeted muscle to or past the POD, but other recent research suggest that submaximal stretching may lead to fewer performance deficits (Knudson et al., 2001, 2004; Young et al., 2006; Manuel et al., 2008). Behm and Kibele (2007) showed equivalent deficits when performing a protocol of 100%, 75% and 50% of 30-second repetitions of SS to the POD targeting the quadriceps, hamstrings and plantar flexors. Results indicated that all conditions reduced jump height with the largest decrease in performance observed in the drop squat and counter movement jump. Interestingly, stretching at 50% intensity led to greater ROM and flexibility compared to 75% and 100%. An additional study by Manuel et al. (2008) implemented a protocol consisting of mild stretching, each stretch required 3 repetitions of 30 seconds; results from Manuel's study found no effects on performance of the knee extensors. Therefore, submaximal SS appears to produce fewer deficits in subsequent performance. However, Bradley et al. (2007) found impairments in vertical jump height following mild SS. Similarly, when Sayer et al. (2008) required participants to perform submaximal SS below the POD, there was an overall decrease in the 30-meter sprint time following the warm-up protocol. The previous two studies required submaximal static stretching, but mild stretching may still decrease performance in skills that require speed and efficient energy transfer. The decrements in performance can also be from SS triggering a decrease in the excitation of the motor neuron pool of the targeted muscle (Power et al., 2004). It has been suggested that less optimal performance from a session of intense SS will attempt to be compensated by a higher stimulation rate, this higher stimulation rate will therefore lead to faster neuromuscular fatigue that can last hours post-stretching (Power et al., 2004). Again, depending on the situation, a recreational athlete who wants to stay healthy and injury free should SS as part of the warm-up to increase ROM and balance performance, whereas an elite athlete, such as a 100-meter sprinter, cannot afford to chance even a small deficit in speed. However this does not preclude incorporating stretching as part of a training routine separate from the warm-up protocol.

1.7 Dynamic Stretching

DS was not the main focus of the literature review but is important to investigate because of the increase in popularity within the athletic community in terms of warm-up protocols prior to an event. Professionals are showing increasing support of DS as the most effective approach for an athlete to prepare prior to an event. By using DS and sports specific movements, DS allows athletes to mimic movement patterns of a particular sport (Young & Behm, 2002). When using DS, it is important that the athlete maintains control throughout the movement by actively bringing the muscles through the desired ROM (Fletcher & Jones, 2004), unlike ballistic stretching which uses a bounce-like movement at the end of the ROM. By mimicking sports specific movements with DS, it will allow athletes to increase central nervous system excitation of motor units (Smith, 1994) and decrease inhibition of antagonist muscles (Jaggers et al., 2008). The DS warm-up protocol can also elevate the core body temperature and increase joint lubrication, assisting with more efficient movement patterns and ROM (Roth & Benjamin, 1979) and increase post- activation potentiation within the stretched muscle (Hough et al., 2009; Turki et al., 2011).

In the context of DS, the literature recommends shorter durations of DS are not as effective in enhancing subsequent performance when compared to DS of 60 seconds or more per exercise (Hough et al., 2009; Pearc et al., 2009). Sekir (2009) used 6 minutes of DS stretching and found an increased concentric torque of the quadriceps (8.4%) and hamstrings (6.8%) and eccentric torque of the quadriceps (14.5%) and hamstrings (14.1%). Showing that prolonged usage of DS (60 seconds and longer) can increase subsequent performance. McMillan et al., (2006) incorporating 10 minutes of DS within the warm-up protocol and showed improved shuttle run time, medicine ball throwing distance and five-step jump distance. Using 7 minutes of DS activity prior to an event, Hough et al., (2009) showed an increase in the vertical jump height and electromyography (EMG) activity, bot no increase in force production. The previous mentioned studies examined typically longer bouts of DS, but even 2-minutes of DS displayed increased EMG activity (Herda, 2008). Additionally, many of the DS research show no change in subsequent performance. Christensen and Nordstrom (2008) used 8 DS exercises x 5 repetitions and found no change in vertical jump height. Where as Papadopoulos et al., (2005) required participants to DS for 30 seconds x 6 repetitions, resulting in no effect on isokinetic torque production. Regardless of the research conducted, additional evidence is required that incorporates SS, DS and sport specific movements in order to determine the most effective warm-up protocols for athletes.

1.8 Full warm-up protocols

Within the athletic community there seems to be unanswered questions as to the precise volume of SS, DS and sports specific movements an athlete should perform prior to an event. Therefore, it is important to continue research that analyzes and manipulates full warm-up protocols and its effect on various performance measures. Many studies have imposed 5-10 min of cycling or jogging at a low intensity (resistance) before subjects completed the testing protocols (Behm et. al., 2004, Behm et al., 2007, Pearce 2009). Some previous investigations have included general aerobic activity either before or immediately following a stretching routine (Behm et al., 2004; Bradley at al., 2007; Barroso et al., 2012). Nevertheless, few studies have incorporated a sports-specific routine following the aerobic and stretching components (Beckett et al., 2009; Kistler et al., 2010; Samson et al., 2012).

There is some evidence that incorporating a full warm-up routine prior to an event, including SS, DS, and sports specific movements, may not lead to impairments from SS but rather enhance physical performance. For example, a lack of effect was observed in a group of elite athletes after combining SS and DS and different intensities of stretching (eight combinations at various intensities and lengths) on sprint, agility, and jump performance (Chaouachi et al., 2010). Kistler et al., (2010) used a full warm-up protocol and found no significant differences in 0-20, 40-60 and 80-100m sprint times but did find a decrease in sprint time during the 20-40-m sprint of 1.4%. Similarly, Gelen (2010) designed warm-up protocols to combine SS and DS while including an aerobic warm-up and found no detrimental effects on athletes' sprint time, soccer dribbling, or soccer penalty kick distance. Samson et al. (2012) showed an improvement in sprint speed following a full warm-up including SS, DS and sports specific movements. When a sports specific warm-up was included, results showed a 0.94% improvement in 20-m sprint time in both the DS and SS conditions. To our knowledge there are few studies that show DS full warm-up protocols impair subsequent performance (Bacurau et al., 2009;

Barroso et al., 2012; Nelson & Kokkonen, 2001; Paradisis et al., 2014; Wallman et al., 2012; Zourdos et al., 2012).

1.9 Conclusion

The primary focus of the literature review was to determine the effects of differing durations and intensities of SS on subsequent performance measures. A warm-up protocol is crucial to pre-event preparation. An efficient and appropriate warm-up protocol can help prepare the participant or athlete for optimal performance. The evidence for muscle stretch-induced performance decrements (see reviews: Behm et al., 2016, Behm & Chaouachi, 2011, Kay & Blazevich, 2012) has led to a paradigm shift in optimal stretching routines within a warm-up. Static muscle stretching (SS) performed prior to an athletic event has been reported to cause mean performance decrements of 5.0-7.5% depending on the duration and intensity of stretching performed (Behm & Chaouachi, 2011, Kay & Blazevich, 2012). Impairments not only occur immediately following a SS intervention but can also last up to two hours following stretching (Power et al., 2004). Therefore, there is a great requirement to determine weather or not various components of a warm-up protocol are enhancing, decreasing or causing no effect on subsequent performance. There should be further research conducted to answer whether or not SS should or should not be incorporated into a warm-up protocol. Additionally, if using SS prior to an event, what durations, intensities and types of SS should be incorporated into a warm-up protocol? Though there is an abundance of evidence showing SS induced impairments in subsequent performance, there is still no concrete answer as to how an athlete and coach can design a warm-up protocol in which there will be no performance decrements.

1.10 Objective

Based on the literature, the objective of the present study is to compare the effect of SS durations of 30, 60, and 120 seconds per muscle group or a control condition with no SS when stretching is accompanied by a full warm-up protocol on subsequent performance and evoked contractile properties.

1.11 Hypothesis

The hypothesis is that a full warm-up protocol involving DS and sports-specific movements will enhance subsequent performance with the control and 30-60 second durations of SS. A second hypothesis is that two minutes of SS per muscle group within a full warm-up will either demonstrate impairments or no significant effect on performance.

1.12 References

Alpkaya, U., & Koceja, D. (2007). The effects of acute static stretching on reaction time and force. *J Sports Med Phys Fit.,*. 47: 147-50.

Amiri-Khorasani, M., Abu Osman, N.A., & Yusof, A. (2011). Acute effect of static and dynamic stretching on hip dynamic range of motion during instep kicking in professional soccer players. *J. Strength Cond. Res.,* 25: 1647-52.

Ayala, F., De Ste Croix, M., Sainz de Baranda, P., and Santonja, F. (2014). Acute effects of static and dynamic stretching on hamstrings' response times. *J. Sports Sci*. 32: 817-25.

Beckett, J.R.J., Schneiker, K.T., Wallman, K.E., Dawson, B.T. and Guelfi, K.J. (2009). Effects of static stretching on repeated sprint and change of direction performance. *Med. Sci. Sports Exerc.* 41: 444-50.

Beedle, B. B., & Mann, C. L. (2007). A comparison of two warm-ups on joint range of motion. *J. Strength Cond. Res.,* 21(3), 776-779.

Beedle, B., Rytter, S.J., Healy, R.C., and Ward, T.R. (2008). Pretesting static and dynamic stretching does not affect maximal strength. *J. Strength Cond. Res*. 22: 1838-1843.

Behm, D. G., Anderson, K., & Curnew, R. S. (2002). Muscle force and activation under stable and unstable conditions. *J. Strength Cond. Res*, *16*(3), 416-422.

Behm, D. G., Button, D. C., & Butt, J. C. (2001). Factors affecting force loss with prolonged stretching. *Can. J. Appl. Physiol.,* 26(3), 262-272.

Behm, D. G., Bambury, A., Cahill, F., & Power, K. (2004). Effect of acute static stretching on force, balance, reaction time, and movement time. *Med. Sci. Sports Excer.*, 36, 1397-1402.

Behm, D. G., & Chaouachi, A. (2011). A review of the acute effects of static and dynamic stretching on performance. *Eur. J. Appl. Physiol.,* 111(11), 2633-2651.

Behm, D. G., Button, D. C., & Butt, J. C. (2001). Factors affecting force loss with prolonged stretching. *Can. J. Appl. Physiol.,* 26(3), 262-272.

Behm, D. G., & Kibele, A. (2007). Effects of differing intensities of static stretching on jump performance. *Eur. J. Appl. Physiol.,* 101(5), 587-594.

Belkhiria-Turki, L., Chaouachi, A., Turki, O., Hammami, R., Chtara, M., Amri, M.,

Boyle, P. M. (2004). The effect of static and dynamic stretching on muscle force production. *J. Sports Sci.,* 22(3), 273.

Bradley, P. S., Olsen, P. D., & Portas, M. D. (2007). The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *J. Strength Cond. Res.*, 21(1), 223-226.

Brooks, V.B. (1986). The neural basis of motor control. NewYork: Oxford University Press.

Burkett, L.N., Phillips, W.T. and Ziuraitis, J. (2005). The best warm-up for the vertical jump in college-age athletic men. *J. Strength Cond. Res*., 19: 673-6.

Cè, E., Margonato, V., Casasco, M., & Veicsteinas, A. (2008). Effects of stretching on maximal anaerobic power: the roles of active and passive warm-ups. *J. Strength Cond. Res.*, 22(3), 794-800.

Chaouachi, A., Castagna, C., Chtara, M., Brughelli, M., Turki, O., Galy, O., Chamari, K., and Behm, D.G. (2010). Effect of Warm-Ups Involving Static or Dynamic Stretching on Agility, Sprinting, and Jumping Performance in Trained Individuals. J. *Strength Cond. Res,*. 24: 2001-2011.

Christensen BK, Nordstrom BJ. (2008). The effects of proprioceptive neuromuscular facilitation and dynamic stretching techniques on vertical jump performance. *J Strength Cond Res*., 22:1826–1831

Cornwall, A., Nelson, A., Sidaway, B. (2002). Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. *Eur. J. Appl. Physiol.,* 86:428–434.

Costa, P.B., Ryan, E.D., Herda, T.J., Walter, A.A., Defreitas, J.M., Stout, J.R. & Cramer, J.T. (2013). Acute effects of static stretching on peak torque and the hamstrings-to-quadriceps conventional and functional ratios. *Scand. J. Med. Sci. Sports*, 23: 38-45.

Cramer, J. T., Housh, T. J., Johnson, G. O., Miller, J. M., Coburn, J. W., & Beck, T. W. (2004). Acute effects of static stretching on peak torque in women. *J. Strength Cond. Res.,* 18(2), 236-241.

Cramer JT, Housh TJ, Weir JP, Johnson GO, Coburn JW, Beck TW. (2005). The acute eVects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. *Eur. J. Appl. Physiol.,* 93:530–539.

Cramer, J.T., Housh, T.J., Johnson, G.O., Weir, J.P., Beck, T.W. and Coburn, J.W. (2007). An acute bout of static stretching does not affect maximal eccentric isokinetic peak torque, the joint angle at peak torque, mean power, electromyography, or mechanomyography. *J. Ortho.Sports Phys Ther.,* 37: 130-9.

Cramer, J.T., Beck, T.W., Housh, T.J., Massey, L.L., Marek, S.M., Danglemeier, S., Purkayastha, S., Culbertson, J.Y., Fitz, K.A., and Egan, A.D. (2007a). Acute effects of static stretching on characteristics of the isokinetic angle - torque relationship, surface electromyography, and mechanomyography. *J. Sports Sci.*, 25: 687-698.

Curry, B.S., Chengkalath, D., Crouch, G.J., Romance, M., and Manns, P.J. (2009). Acute effects of dynamic stretching, static stretching, and light aerobic activity on muscular performance in women. *J. Strength Cond. Res*.,. 23: 1811-1819.

Duncan, M.J. and Woodfield, L.A. (2006). Acute effects of warm-up protocol on flexibility and vertical jump in children. *J. Exerc. Physiol*., 9: 9-16.

Ebben, W. P., & Blackard, D. O. (2001). Strength and conditioning practices of National Football League strength and conditioning coaches. *J. Strength Cond. Res., 15*(1), 48-58.

Ebben, W. P., Carroll, R. M., & Simenz, C. J. (2004). Strength and conditioning practices of National Hockey League strength and conditioning coaches. *J. Strength Cond. Res.,18*(4), 889-897.

Ebben, W. P., Hintz, M. J., & Simenz, C. J. (2005). Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *J. Strength Cond. Res., 19*(3), 538-546.

Fletcher, I. M., & Jones, B. (2004). The effect of different stretch protocols on 20 meter sprint performance in trained rugby union players. *J. Strength Cond. Res., 18(4),* 885-888.

Fletcher, I. M. (2010). The effect of different dynamic stretch velocities on jump performance. *Eur. J. Appl. Physiol., 109*(3), 491-498.

Fletcher, I. M., & Jones, B. (2004). The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *J. Strength Cond. Res* .,18(4), 885-888.

Fletcher, I. M., & Anness, R. (2007). The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. *J. Strength Cond. Res.*, *21*(3), 784-787.

Fletcher, I.M. and Monte-Colombo, M.M. (2010). An investigation into the possible physiological mechanisms associated with changes in performance related to acute responses to different preactivity stretch modalities. *Appl. Physiol. Nutr. Metab.* 35: 27-34.

Fortier, J., Lattier, G. and Babault, N. (2013). Acute effects of short-duration isolated static stretching or combined with dynamic exercises on strength, jump and sprint performance. *Sci. Sports*. 28: 111-7.

Fowles, J. R., Sale, D. G., & MacDougall, J. D. (2000). Reduced strength after passive stretch of the human plantarflexors. *J. Appl. Physiol.,* 89(3), 1179-1188.

Franco, B. L., Signorelli, G. R., Trajano, G. S., & de Oliveira, C. G. (2008). Acute effects of different stretching exercises on muscular endurance. *J. Strength Cond. Res., 22*(6), 1832-1837.

Gajdosik, R. L., Vander Linden, D. W., McNair, P. J., Williams, A. K., & Riggin, T. J. (2005). Effects of an eight-week stretching program on the passive-elastic properties and function of the calf muscles of older women. *Clin. Biomech.*, *20*(9), 973-983.

Gelen, E. (2010). Acute effects of different warm-up methods on sprint, slalom dribbling, and penalty kick performance in soccer players. *J. Strength Cond. Res.,* 24(4), 950-956.

González-Ravé, J. M., Machado, L., Navarro-Valdivielso, F., & Vilas-Boas, J. P. (2009). Acute effects of heavy-load exercises, stretching exercises, and heavy-load plus stretching exercises on squat jump and countermovement jump performance. *J. Strength Cond. Res*., 23(2), 472-479.

Guyton, A. C., & Hall, J. E. (1996). Contraction of skeletal muscle. *Textbook of medical physiology*, *7*.

Haddad, M., Dridi, A., Chtara, M., Chaouachi, A., Wong, D. P., Behm, D., & Chamari, K. (2014). Static stretching can impair explosive performance for at least 24 hours. *J. Strength Cond. Res., 28*(1), 140-146.

Haghshenas, R.T.-B., I.; Avandi, S. M. (2014). Acute effect of different warm-up stretch protocols on vertical jump performance in volleyball players. Inter. *J. Sport Studies* 4: 907-913.

Handel, M., Horstmann, T., Dickhuth, H. H., & Gülch, R. W. (1997). Effects of contract-relax stretching training on muscle performance in athletes. *Eur. J. Appl. Physiol.*, 76(5), 400-408.

Herda, T. J., Cramer, J. T., Ryan, E. D., McHugh, M. P., & Stout, J. R. (2008). Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *J. Strength Cond. Res.,* 22(3), 809-817.

Herda, T. J., Ryan, E. D., Costa, P. B., Walter, A. A., Hoge, K. M., Uribe, B. P., ... & Cramer, J. T. (2010). 4 Acute effects of passive stretching and vibration on the electromechanical delay and musculotendinous stiffness of the plantar flexors. *Electromyogr. Clin. Neurophysiol.*, *50*(6), 277.

Hough PA, Ross EZ, Howatson G. (2009). Effects of dynamic and static stretching on vertical jump performance and electromyo- graphic activity. *J. Strength Cond. Res*., 23:507–512

Houglum, P. A. (2001). Therapeutic exercise for athletic injuries. Human Kinetics.

Hunter, J. P., & Marshall, R. N. (2002). Effects of power and flexibility training on vertical jump technique. *Med. Sci. Sports Exerc.,*34(3), 478-486.

Jaggers, J. R., Swank, A. M., Frost, K. L., & Lee, C. D. (2008). The acute effects of dynamic and ballistic stretching on vertical jump height, force, and power. *J. Strength Cond. Res.*, 22(6), 1844-1849.

Kay, A. D., & Blazevich, A. J. (2012). Effect of acute static stretch on maximal muscle performance: a systematic review. *Med Sci Sports Exerc*, 44(1), 154-164.

Kirmizigil, B., Ozcaldiran, B., & Colakoglu, M. (2014). Effects of three different stretching techniques on vertical jumping performance. *J. Strength Cond. Res*. 28: 1263-71.

Kistler, B.M., Walsh, M.S., Horn, T.S. and Cox, R.H. (2010). The acute effects of static stretching on the sprint performance of collegiate men in the 60- and 100-m dash after a dynamic warm-up. *J. Strength Cond. Res*. 24:2280-4.

Knudson D, Bennett K, Corn R, Leick D, Smith C. (2001). Acute effects of stretching are not evident in the kinematics of the vertical jump. *J Strength Cond Res* 15:98–101

Knudson, D., & Noffal, G. (2005). Time course of stretch-induced isometric strength deficits. *Eur. J. Appl. Physiol*., 94(3), 348-351.

Kokkonen, J., Nelson, A. G., & Cornwell, A. (1998). Acute muscle stretching inhibits maximal strength performance. *Res. Q. Exerc. Sport*, 69(4), 411-415.

Little, T., Williams, A.G. (2006) Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *J. Strength Cond. Res*., 20:203–207

McMillian, D. J., Moore, J. H., Hatler, B. S., & Taylor, D. C. (2006). Dynamic vs. static-stretching warm up: the effect on power and agility performance. *J. Strength Cond. Res.,* 20(3), 492-499.

Moss, D. (2002). Sport science: Static stretching before exercise reduces explosive power.

Physical Education Digest, 19(2), 24-25.

Nakamura, M., Ikezoe, T., Takeno, Y., & Ichihashi, N. (2011). Acute and prolonged effect of static stretching on the passive stiffness of the human gastrocnemius muscle tendon unit in vivo. *J. Orthop. Sports Phys.,* ,29(11), 1759-1763.

Nelson, A. G., & Kokkonen, J. (2001). Acute ballistic muscle stretching inhibits maximal strength performance. *Res. Q. Excerc. Sport*, 72(4), 415-419.

Nelson, A. G., Allen, J. D., Cornwell, A., & Kokkonen, J. (2001). Inhibition of maximal voluntary isometric torque production by acute stretching is joint-angle specific. *Res. Q. Excer. Sport*, 72(1), 68-70.

Nelson, A. G., Guillory, I. K., Cornwell, A., & Kokkennen. N, J. (2001). Inhibition of maximal voluntary isokinetic torque production following stretching is velocity-specific. *J. Strength Cond. Res.*, 15(2), 241-246.

Ogura Y, Miyahara Y, Naito H, Katamoto S, Aoki J (2007) Duration of static stretching influences muscle force production in hamstring muscles. *J. Strength Cond. Res.*, 21:788–792

Papadopoulos, G., Siatras, T. H., & Kellis, S. (2005). The effect of static and dynamic stretching exercises on the maximal isokinetic strength of the knee extensors and flexors. *Isokinetic Excer. Sci.*, 13(4), 285-291.

Pearce AJ, Kidgell DJ, Zois J, Carlson JS (2009) Effects of secondary warm up following stretching. *Eur. J. Appl Physiol.*, 105:175–183

Potach, D. H. (2004). Plyometric and speed training: plyometric mechanics and physiology. In T. Baechle & R. Earle, (Eds.), *Essentials of personal training* (pp. 268-269). Champaign, IL: Human Kinetics.

Power, K., Behm, D., Cahill, F., Carroll, M., & Young, W. (2004). An acute bout of static stretching: effects on force and jumping performance. *Med. Sci. Sports Exerc.*, 36, 1389-1396.

Roth, P., & Benjamin, B. (1979). Warming up vs. stretching: Why the top runners don't do much stretching before running. *Running Times, 34,* 15-21.

Samuel, M. N., Holcomb, W. R., Guadagnoli, M. A., Rubley, M. D., & Wallmann, H. (2008). Acute effects of static and ballistic stretching on measures of strength and power. *J. Strength Cond. Res.*, 22(5), 1422-1428.

Sekir U, Arabaci R, Akova B, Kadagan SM (2009) Acute effects of static and dynamic stretching on leg flexor and extensor isokinetic strength in elite women athletes. *Scand J Med Sci Sports. 20(2), 268-281.*

Siatras, T. A., Mittas, V. P., Mameletzi, D. N., & Vamvakoudis, E. A. (2008). The duration of the inhibitory effects with static stretching on quadriceps peak torque production. *J. Strength Cond. Res.*, 22(1), 40-46.

Siatras, T. A., Mittas, V. P., Mameletzi, D. N., & Vamvakoudis, E. A. (2008). The duration of the inhibitory effects with static stretching on quadriceps peak torque production. *The Journal of Strength & Conditioning Research*, *22*(1), 40-46.

Sim, A.Y., Dawson, B.T., Guelfi, K.J., Wallman, K.E. and Young, W.B. (2009). Effects of static stretching in warm-up on repeated sprint performance. *J. Strength Cond. Res.*, 23: 2155-62.

Simenz, C. J., Dugan, C. A., & Ebben, W. P. (2005). Strength and conditioning practices of National Basketball Association strength and conditioning coaches. *J. Strength Cond. Res.*,*19*(3), 495-504.

Smith, C. A. (1994). The warm-up procedure: to stretch or not to stretch. A brief review. *J Orthop Sports Phys Ther*., 19(1), 12-17.

Taylor, D. C., Dalton, J. D., Seaber, A. V., & Garrett, W. E. (1990). Viscoelastic properties of muscle-tendon units the biomechanical effects of stretching. *Am J Sports Med*., 18(3), 300-309.

Turki O., Chaouachi A., Drinkwater E.J., Chtara M., Chamari K., Amri M. and Behm D.G. Ten minutes of dynamic stretching is sufficient to potentiate vertical jump performance characteristics. *J. Strength Cond. Res*., 25(9): 2453-2463, 2011

Unick, J., Kieffer, H. S., Cheesman, W., & Feeney, A. (2005). The acute effects of static and ballistic stretching on vertical jump performance in trained women. *J. Strength Cond. Res*., 19(1), 206-212.

Vetter, R. E. (2007). Effects of six warm-up protocols on sprint and jump performance. *J. Strength Cond. Res*., 21(3), 819-823.

Wallmann, H.W., Mercer, J.A. and McWhorter, J.W. 2005. Surface electromyographic assessment of the effects of static stretching of the gastrocnemius on vertical jump performance. *J. Strength Cond. Res.,* 19: 684-8.

Wilson, G. J., Elliott, B. C., & Wood, G. A. (1991). The effect on performance of imposing a delay during a stretch-shorten. *Med. Sci. Sports Excer.,* 23(3), 364.

Winchester, J.B., Nelson, A.G., Landin, D., Young, M.A. and Schexnayder, I.C. 2008. Static stretching impairs sprint performance in collegiate track and field athletes. *J. Strength Cond. Res.,* 22: 13-8.

Worrell T, Smith T, Winegardner J (1994) Effect of hamstring stretching on hamstring muscle performance. *J. Orthop. Sports Physical Ther.,* 20:154–159

Yamaguchi, T., & Ishii, K. (2005). Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. *J. Strength Cond. Res.*, 19(3), 677-683.

Young, W., Elias, G., & Power, J. (2006). Effects of static stretching volume and intensity on plantar flexor explosive force production and range of motion. *J. Sports Med. Phys. Fitness., 46*(3), 403.

Young, W. B., & Behm, D. G. (2002). Should Static Stretching Be Used During a Warm-Up for Strength and Power Activities? *J. Strength Cond. Res.*, 24(6), 33-37.

Young, W. B. (2007). The use of static stretching in warm-up for training and competition. *Int. J. Sports Physiol. Perform., 2*(2), 212.

Chapter 2: Co- Authorship Statement

The following details my role of the manuscript.

Research Design

Methodology was developed based on previous research by Dr. David Behm in combination with work from static and dynamic stretching, warm-up protocols and athlete performance. Discussions with Dr. David Behm helped to refine details of the experiment. With assistance from Dr. David Behm I was able to obtain approval from the Health Research Ethics Authority (HREA) to conduct this research.

Data Collection

I collected all data with assistance from Dr. David Behm.

Data Analysis

I performed all data analysis procedures with the help of Rebecca Greene.

Manuscript Preparation

I wrote the manuscript with assistance from Dr. David Behm and James Young.

Chapter 3: Manuscript

The global effects of differing durations of static stretching within a full warm-up protocol on subsequent voluntary performance and evoked contractile properties.

Authors: Reid Jonathan C, Greene Rebecca, Young James D, Hodgson Daniel D and Dr. David Behm

Institution: School of Human Kinetics and Recreation

Memorial University of Newfoundland

St. John's, Newfoundland, Canada, A1M 3L8

3.1 Abstract

Introduction: The growing evidence portraying performance decrements following prolonged static stretching (SS)(>60s per muscle group) has led to a paradigm shift in optimal stretching routines within a warm-up. Many athletic teams and individuals have now incorporated dynamic stretching (DS) and dynamic activity (DA) rather than SS into their pre-exercise warm-up routines. The objective of the present study was to compare the effect of differing SS durations within a warm-up protocol consisting of additional aerobic and dynamic stretching and activity (DS/DA) components. **Methods:** Sixteen male participants (Sixteen males; 27.6 ± 2.15 years, 187.1 ± 15.3 lb. and 181.9 ± cm) with an athletic background and at least 2 years of strength or endurance training experience completed four warm-up protocol conditions. Each condition included a submaximal 5-minute aerobic warm-up component on a cycle ergometer, a DS/DA component, and one of four SS interventions (30, 60 or 120s SS per muscle group or control). Tests included performance measures (range of motion (ROM), maximum voluntary contractions (MVC), explosive force production (F100), vertical jump height) and voluntary and evoked contractile properties. **Results:** For hamstrings ROM, the SS 120s condition provided the largest increase (5.6-11.7%, almost certain) followed by SS 60s (4.3-11.4%, likely- almost certain), control (4.4-10.6%, very likely to almost certain) and SS 30s (3.6-11.1%, likely to almost certain) conditions. For quadriceps ROM, the SS 30s condition provided the largest increase (9.3-18.2 %, very likely- almost certain) followed by SS 120s (6.5- 16.3%, likely-almost certain), SS 60s (7.2- 15.2%, likely-almost certain) and control (6.3- 15.2%, likely- almost certain) conditions. There were decreases in quadriceps F100 following the SS intervention in the SS 120s condition

(29.6%, likely). There were increases in vertical jump performance following the SS intervention in the control (6.2%, almost certain), SS 60s (4.6%almost certain) and SS 30s (3.3%, almost certain) conditions. **Conclusions:** Previous research analyzing the effects of full warm-up protocols generally demonstrates no change or an increase in performance. It is believed that fatigue from the warm-up protocols and testing measures plus impairments from prolonged SS, even with the inclusion of / DA may still generate impairments in some performance measures.

Key words: Dynamic stretching (DS), Dynamic Activity (DA), Range of motion (ROM), Vertical jump, Force production.

3.2 Introduction

The evidence for muscle stretch-induced performance decrements (see reviews: Behm et al., 2016, Behm & Chaouachi, 2011, Kay & Blazevich, 2012) has led to a paradigm shift in optimal stretching routines within a warm-up. Static muscle stretching (SS) performed prior to an athletic event has been reported to cause mean performance decrements in various performance measures of 5.0-7.5% depending on the duration and intensity of stretching performed (Behm & Chaouachi, 2011, Kay & Blazevich, 2012). Impairments not only occur immediately following a SS intervention but can last up to two hours following the stretching intervention (Power et al., 2004). In view of the bulk of SS-induced impairment evidence, many athletic teams and individuals have now incorporated dynamic stretching (DS) rather than SS into their pre-exercise warm-up routines (Ebben & Blackard, 2001, Ebben et al., 2004, 2005, Simenz et al., 2005).

It has been suggested that DS leads to superior physiological performances compared to SS due to the closer similarity of movement patterns between DS and subsequent exercises (Torres et al., 2008). Research examining the effects of DS has typically revealed a performance enhancement or lack of significant effect, particularly when each DS exercise is performed for 60 seconds or longer (Behm et al., 2016, Behm & Chaouachi, 2011). Studies implementing DS have reported both facilitation of muscular power (Manoel et al., 2008), as well as sprint (Fletcher & Anness, 2007; Little & Williams, 2006) and jump performances (Holt & Lambourne, 2008) with no adverse effects reported (Samuel et al., 2008; Torres et al., 2008; Unick et al., 2005). SS research has revealed impairments after holding SS for 60 seconds or longer (Behm et al., 2016, Chaouachi & Behm, 2011, Kay & Blazevich, 2012); however, some studies have illustrated impairments with less than 60 seconds of SS per muscle group (Fletcher & Monte- Colombo, 2010, Hough et al., 2009, Vetter, 2007, Fletcher & Jones, 2004).

Of note however, is that much of the previous research examining the effects of SS and DS did not incorporate all the components of a full sport specific warm-up used in a typical athletic setting (Ebben & Blackard, 2001, Ebben et al., 2004, 2005, Simenz et al., 2005). Many studies have imposed 5-10 minutes of cycling or jogging at a low intensity (resistance) before participants completed the testing and experimental protocols (Behm et. al., 2004, Behm et al., 2007, Pearce, 2009). Some previous investigations have included general aerobic activity either before or immediately following a stretching routine (Behm et al., 2004; Bradley at al., 2007; Murphy et al., 2010). Nevertheless, few studies have incorporated a sports-specific routine following the aerobic and stretching components (Beckett et al., 2009; Kistler et al., 2010; Samson et al., 2012).

There is some evidence that incorporating a full warm-up routine with the inclusion of SS prior to an event may not lead to impairments in performance but rather enhance physical performance. For example, a lack of effect was observed in a group of elite athletes after combining SS and DS and different intensities of stretching (eight combinations at various intensities and lengths) on sprint, agility, and jump performance (Chaouachi et al., 2010). Kistler et al., (2010) used a full warm-up protocol, having participant's complete 25-minute warm-ups that included an 800-m jog, dynamic movements that mimic sprinting as well as hurdle and mobility drills. Kistler found no significant differences in 0-20, 40-60 and 80-100m sprint times but did find a decrease in sprint time during the 20-40-m sprint of 1.4%. Similarly, Gelen (2010) designed full warm-up protocols that included SS, DS and an aerobic warm-up and found no detrimental effects on athletes' sprint time, soccer dribbling, or soccer penalty kick distance. Supporting enhanced performance following a full warm-up protocol, a study conducted by Sekir et al. (2009) had participants perform dynamic and ballistic stretching at slow and fast movements within a warm-up protocol. Results from Sekir's study demonstrated an enhanced concentric and eccentric torque of the hamstrings and quadriceps in each conditon. Samson et al. (2012) showed an improvement in sprint speed following a full warm-up including SS, DS and sports specific movements. When a sports specific warm-up was included, results showed a 0.94% improvement in 20-m sprint time in both the DS and SS conditions. To our knowledge there are few studies that show DS full warm-up protocols impair subsequent performance (Bacurau et al., 2009; Nelson & Kokkonen, 2001; Paradisis et al., 2014).

The objective of the present study was to compare the effect of SS durations of 30, 60, and 120 seconds per muscle group or a control condition (with no SS) when stretching is includes a full warm-up protocol. It was hypothesized that a full warm-up protocol involving DS and sports-specific dynamic movements will enhance subsequent performance in the control, 30 and 60 seconds of SS conditions. A second hypothesis is postulated that two minutes of SS per muscle group within a full warm-up protocol will demonstrate impairments in performance.

3.3 Methodology

Participants:

There were 16 healthy male participants (Sixteen males; 27.6 ± 2.15 years, 187.1 ± 15.3 lb. and 181.9 ± cm) with no pre-existing musculoskeletal or neurological conditions and who was currently at least 2 years of strength and or endurance trained. Participants that had experienced any recent musculoskeletal injuries, currently taking pain medications or any other medications that may inhibit maximal performance were not eligible for testing. Participants were instructed to refrain from consuming alcohol and caffeine 24 and 6 hours prior to testing, respectively. Each participant read and signed a Physical Activity Participation Questionnaire (PAR- Q: Canadian Society for Exercise Physiology) ensuring a healthy status. Participants were required to read and sign an informed consent form. Participants were assured they could withdraw from the experiment at any time. Ethical approval was granted by the institution's Health Research Ethics Authority (Approval Code: 2017035) and adheres to the Declaration of Helsinki.

Experimental Design:

There were four conditions: SS of 30, 60, and 120 seconds per muscle group and a control session without a SS intervention. Each condition included a prior submaximal aerobic warm-up on a cycle ergometer, one of the four SS interventions and subsequent DS/DA component. There was a 1-minute rest period following each component or intervention within the warm-up protocol (aerobic, SS, DS/DA and 10-minute rest period). There was also a 30 second rest period between each of the SS and DS/DA exercises. Performance tests were conducted during pre-test measurements and following the aerobic component, SS intervention, DS/ DA component and 10-minute rest period. Overall, each of the four warm-up protocol conditions was approximately 60 minutes in duration. Performance tests consisted of knee extensor and flexor isometric maximal voluntary contractions (MVC), evoked twitch contractile properties, vertical jump height and range of motion (ROM). ROM measures were taken using a passive supine straight leg hip flexion (hamstrings flexibility) and a modified knee flexion from a lunge position (quadriceps flexibility) test. Refer to figure 1 for additional experimental design details.

Testing Measures:

Evoked contractile properties:

Evoked contractile properties were recorded prior to MVCs. Peak twitch torques were evoked using bipolar surface stimulating electrodes. The cathode was secured over the femoral triangle and the anode over the greater trochanter. Both electrodes were connected to a high-voltage stimulator (Digitimer Stimulator Model DS7AH, Hertfordshire, UK). The current intensity (10 mA-1A) and duration (200 μs) of a 400 V square wave pulse was progressively increased until a maximum twitch torque was achieved. The location of the electrodes may have slightly varied each day in order to find the optimum stimulus response at low intensity before testing began. The average of three trials was used to measure the peak muscle action potential wave and duration (M-wave and M-wave duration), twitch torque amplitude (PT), time to peak twitch torque (TPT), and electromechanical delay (EMD). Electromechanical delay was measured from the onset of muscle activation until the moment force was produced. Excellent intersession reliability has been reported in a number of publications from this laboratory (Johar P et al., 2012; Drinkwater & Behm 2007; Behm et al., 2003).

Knee Extensors and Flexor MVC Force

Prior to the pre-tests, the participants performed five submaximal isometric knee extensor contractions, three at 50% of perceived maximum exertion followed by two at 80% of perceived maximum. For the knee extension and flexion MVC's, participants were seated on a bench with their hips and knees flexed at 90° or 120° respectively. Restraints were placed over the quadriceps, across the hips, and around the chest to ensure consistency of joint angles and minimize extraneous movement. The ankle was attached using a padded strap, with a high-tension wire connected to a Wheatstone bridge configuration strain gauge (Omega Engineering Inc. LCCA 250, Don Mills, ON). All voluntary and evoked torques were detected by strain gauges, amplified (x1000)(Biopac Systems Inc., DA 100: analog-digital converter MP100WSW, Holliston, MA) and directed to a computer. Data was sampled at 2000 Hz and analyzed with a commercially designed software program (AcqKnowledge III, Biopac Systems Inc.). Knee extension and flexion MVC's were sustained for 4 seconds. Participants were instructed to contract as quickly and powerfully as possible for the full duration of each MVC. Data analysis included peak MVC forces as well as the instantaneous strength defined as the force produced in the first 100 milliseconds (F100). The reliability of these tests has been shown to be excellent in previously published papers from this laboratory (Šambaher N, 2016; Kawamoto et al., 2014; Halperin et al., 2014).

Interpolated Twitch Technique (ITT)

The ITT has been reported to be a valid and reliable measure of muscle voluntary activation (Behm et al., 1996, Behm, 2009). The electrode configuration and current for the maximal evoked twitches were used for the ITT. The ITT involved superimposing an electrically stimulated doublet (100 Hz) with an inter-pulse interval of 10 ms at 2.5 seconds of the 4 second MVC. An interpolation ratio was calculated comparing the amplitude of the superimposed doublet with a post contraction potentiated doublet (2 seconds following the MVC) to estimate the extent of voluntary activation during a voluntary contraction (1- (interpolated doublet force / potentiated doublet force) x 100) = % of muscle voluntary activation (Behm et al., 1996; Button et al., 2008).

Electromyography (EMG)

Muscle electromyogram (EMG) was recorded from the vastus lateralis and bicep femoris during MVC, evoked and ITT twitch contractions. The EMG electrodes remained in the same place for the full duration of the warm-up protocol and for all testing measures. EMG was recorded during each of the hamstrings and quadriceps MVC's. Thorough skin preparations for all recording electrodes included removal of body hair and epithelial cells with a razor around the designated areas. Followed by cleansing of the designated areas with an isopropyl alcohol swab. EMG recording bipolar electrodes (MediTrace Pellet Ag/AgCl electrodes, Graphic Controls Ltd., Buffalo, NY) were placed (dimensions 3.2 cm) over the mid-belly of vastus lateralis halfway from the anterior superior iliac spine to the apex of the patella and long head of biceps femoris halfway from the gluteal fold to the popliteal space. Ground electrodes were secured on the fibular head (Behm et al., 2002; Mesin et al., 2009; McDonald et al., 2013). EMG activity was amplified x (1000), band- pass filtered (10–1000 Hz), rectified and directed to a computer. The integrated EMG (iEMG) activity was then determined over a 1s period (0.5 s prior to and 0.5s following the peak torque) during the MVC. EMG reliability has been shown to be excellent in previously published papers from this laboratory (Sambaher et al., 2016; Behm et al., 2002; Kawamoto et al., 2014; Halperin et al., 2014).

Vertical Jump Test

A jump-and-reach system (Vertec, Swift Performance Equipment. Lismore, Australia) was used for the vertical jump to directly measure jump height based on the difference between reach height and jump height obtained. The Vertec device has 100 colour-coded, movable vanes that are each spaced 1 cm apart. Reach height was obtained before each session with the participant standing in a static erect position underneath the Vertec device while reaching as high as possible with the arm touching their ear throughout the reach. A self-selected standing position was assumed directly beside the device and this position was to be kept consistent across all testing sessions. When ready, the participant executed a two-foot vertical jump to displace the highest Vertec vanes with the dominant hand. The jump height was recorded as the number below the score reflected on the Vertec device to accurately show the vertical height jumped. Each participant was given a maximum of two attempts per round of testing. The best score was used for analysis and a 30-s rest was imposed between each jump. Vertical jump reliability has been shown to be excellent in previously published papers from this laboratory (Hodgson et al., 2017 & Power et al., 2004).

Supine Hip Flexion ROM

Static flexibility is defined as the ROM that is available to a joint or series of joints (Gleim & Mchugh 1997). Passive hip flexion ROM was measured using a manual goniometer (Baseline 360 Degree Head 12-inch arm plastic goniometer. Fabrication Enterprises, White Plains, New York) and a supine hip flexion test (Hodgson et al., 2017). The goniometer was accurate to 1 cm. While measuring ROM, the research assistant helped to lift the leg through the ROM while the primary researcher used the goniometer. This technique involved placing the participant in a supine position and ensuring both knees remained in full extension. The participant's leg was passively raised to induce flexion at the hip with minimal hip rotation until the participant verbally indicated the point of discomfort was reached. The point of discomfort was described to the participants as the point at which they felt the onset of uncomfortable tension in the hamstrings. During the leg raise, no movement of the contralateral leg was ensured. The participant was instructed to remain relaxed and to avoid any voluntary contractions. The angle measured was the angle between the long axis of the thigh and the long axis of the torso, thus we used the greater trochanter as the axis of rotation. The maximum angle of the hip flexion achieved was recorded. ROM data was calculated by subtracting post-test values from pre-test values for each condition. Two trials were performed with the mean used for analysis. Hamstrings ROM reliability has been shown to be excellent in previously published papers from this laboratory (Hodgson et al., 2017; Murphy et al., 2010; MacDonald et al., 2013).

Quadriceps lunge position ROM

To assess knee joint ROM, the subjects were asked to perform a modified kneeling lunge (Hodgson et al., 2017). To perform properly, it was ensured subjects had their torso in an upright and erect position, placing their back knee in line with their back ankle and aligning their lower back leg perpendicular to the floor. Participants were instructed to position themselves so that the back dominant leg was stretched to the point of discomfort with the front non-dominant leg at a 90-degree angle. Quadriceps ROM was performed passively. Passive quadriceps ROM was measured by the researcher who measured the ROM with the manual goniometer while the research assistant helped to bring the dominant leg through the ROM. Knee joint ROM measurements were taken using a manual goniometer and the maximum angle at the knee joint was recorded. Quadriceps ROM reliability has been shown to be excellent in previously published papers from this laboratory (Hodgson et al., 2017; Grabow et al., 2017).

Interventions:

Following the pre-test, the experimental sessions commenced with a dynamic warm-up on a cycle ergometer (Monark; Ergomedic 828E) at 60-70- rpm with a resistance of 1-kp (70 Watts) for 5-minutes.

Using a random allocation selection on separate testing days, participants performed one of the four SS interventions. The control condition required participants to perform the aerobic and DS components without a SS intervention. Instead of a SS intervention, participants took a 60 second rest period and then proceeded to the post-SS testing measures. Following the pre-test and aerobic warm-up tests, participants performed SS on two muscle groups for durations of 30s (3x10), 60s (3x20), and 120s (3x40) and a control condition with no stretching or activity interventions. The SS movements targeted the quadriceps, and hamstrings muscle groups. The quadriceps SS had participants in a standing erect static position with feet shoulder width apart. One leg was fully extended and on the ground while the other leg was off the ground, flexed at the knee and pulled towards the gluteal muscles with the opposing hand. Participants emphasized on elongating the quadriceps of the back leg while keeping the core contracted and balance maintained. The hamstring SS had participants place the heel of one leg on a small bench 15 cm in height. The participants pressed the heel into the bench while pointing the toes upwards, pushing the hips back and maintaining a neutral spine. The opposing leg was fully extended and planted on the ground. Subjects continued to push the hips back until hamstring tension was at the point of discomfort (POD).

Warm-up Components

Immediately following the completion of the SS condition, participants proceeded to perform the DS/DA component. The DS/DA included 1 repetition of 60 seconds for all exercises except the high knees and gluteal kicks which were separated into 30 seconds each. The DS/DA included: walking hip openers, dynamic leg kicks to opposing hand, high knees, and gluteal kicks combined, walking lunges with a rotation and the inchworm. All stretches were performed to a full ROM at a moderate speed with a continuous motion except for the lunge with a rotation and the inchworm, which required more time to execute properly. Participants were instructed not to exceed their POD or cause any pain while performing the dynamic movements.

The hip openers required participants to flex the knee and hip to 90-degrees, from this position the hip was externally rotated while maintaining the 90-degree hip and knee angle and then brought back to the original position. The lunge with a rotation required participants to take a step forward while keeping the chest elevated and flexing the front and back leg to roughly 90 degrees. The back leg remained roughly 1-2 cm above the ground while performing the rotation portion of the exercise. In the bottom of the lunge position, participants planted the opposite arm as the front lunge leg on the ground with the arm fully extended. The opposing arm was rotated towards the midline of the body while the lunge position was maintained. For the high knees component, participants were directed to flex the hip and knee to 90 or slightly above 90 degrees. Throughout the high knees dynamic movement, subjects would explosively drive the knee towards the chest similar to when performing a sprint. Gluteal kicks had participants jog whilst flexing the knee until the heel touched the gluteal region with the foot dorsiflexed for each step taken. Walking leg kicks consisted of kicking the opposing hand by flexing the hip and keeping the knee slightly bent. For the gluteal kicks and high knees DS/DA, participants were instructed to perform one repetition per second. Lastly, the inchworm required participants to start in a standing, erect position. Participants were instructed to use the hands to walk the body into a high plank position by hinging at the hips, keeping the lower back neutral and core contracted. Once the high plank position was achieved, participants proceeded to walk back into a standing erect position by walking the legs towards the upper body. The legs were to be as extended as possible to emphasize hamstring and calf ROM while subjects moved back into a standing start position. Between each repetition of stretching (SS, DS/DA) there was a rest period of 15 seconds.

Statistical analysis:

The inappropriateness of null-hypothesis significance testing for assessing clinical or practical importance has been noted in the fields of sports medicine (Hopkins et al. 2009), as well as statistics (Ludbrook & Dudley, 1998). Therefore, the results of this present study were interpreted using meaningful differences in a magnitude-based approach for analysis and reporting (Hopkins, 2004). Effect sizes (ES) are a detailed method of dividing the change score by the standard deviation (SD) of the raw data to arrive at a standard ES (Cohen. 1988). Cohen's *d* values of 0.2, 0.6 and 1.2 were used to determine if the effect sizes were small, medium and large respectively (Drinkwater et al., 2007). The percent likelihood that the observed effect size was larger than the smallest worthwhile change (ES: 0.2) was calculated based on previous methods (Drinkwater et al., 2007; Hopkins, 2004, 2009). Chances of a meaningful difference were classified qualitatively as follows: <1%, almost certainly not; <5%, very unlikely; <25%, unlikely; 25–75%, possible; >75%, likely; >95%, very likely; >99% almost certain. The ≥75%, likely, classification was used as the threshold for a meaningful difference (Hamilton, 2017, Drinkwater et al., 2007). Additionally, percentage differences and confidence intervals were reported. Reliability measures for all dependent variables as assessed with Cronbach alpha intraclass correlation coefficients (ICC) ranged from good to excellent. (Table 1)

3.4 Results

Hamstrings ROM:

The SS 120s condition provided the largest increase in ROM (5.6-11.7%, almost certain) followed by SS 60s (4.3-11.4%, likely- almost certain), control (4.4-10.6%, very likely to almost certain) and SS 30s (3.6-11.1%, likely to almost certain) conditions when compared to the pre-test.

There were increases in ROM following the SS interventions in all conditions. The largest increase in ROM was in the **SS 120s** condition **(**9.2%, almost certain), followed by **SS 60s** (8.1%, almost certain), **Control (**7.8%, almost certain) and **SS 30s (**4.9%, almost certain) conditions. In all conditions, following the DS/DA component of the warm-up, there was an additional increase in ROM when compared to ROM following SS interventions (**SS 30s:** 6.3%, almost certain; **SS 60s:** 3.3%, almost certain; **Control:** 2.8%, almost certain and **SS120s:** 2.5%, almost certain).

In all conditions, the 10-minute rest period ROM remained higher than pre-test ROM (**SS 120s:** 11.1%, almost certain; **SS 60**s: 10.1%, almost certain; **Control:** 9%, almost certain and **SS 30s:** 8.7%, almost certain). (Table 2)

Comparisons between conditions:

The SS 120s condition provided additional increases in hamstrings ROM following the SS intervention (3%, likely) and DS/DA component (3%, likely) when compared to the control condition. Ten-minutes following the full warm-up protocol there were near meaningful increases in ROM when comparing SS 120s to the control condition (possible; 71%). There were no other meaningful differences between conditions. (Table 18)

Quadriceps ROM:

The **SS 30s** condition provided the largest increase in ROM (9.3-18.2 %, very likely-almost certain) followed by **SS 120s** (6.5- 16.3%, likely-almost certain), **SS 60s** (7.2-

15.2%, likely- almost certain) and **Control** (6.3- 15.2%, likely- almost certain) conditions.

When compared to the pre-test, increases in ROM following the SS interventions were evident in all conditions. The largest increase in ROM was in the SS 30s condition (13.6%, almost certain), followed by SS 120s (13.2%, almost certain), control (11.1%, very likely) and SS 60s (10.8%, likely) conditions. In all conditions, there were decreases in quadriceps ROM when comparing the 10-minute rest period to DS/DA component ROM (**SS 60s:** -4.1%; **SS 120s:** -3.5%; **Control:** -2.5% and **SS 30s:** -0.2%). Ten-minutes following the warm-up protocol, quadriceps ROM remained higher than all pre-test measurements (**SS 30s:** 18%, almost certain; **Control:** 15.2%, almost certain; **SS 120s:** 12.8%, almost certain and **SS 60s:** 11.5%, likely). (Table 3)

Comparisons between conditions:

There were additional increases in quadriceps ROM following the DS/DA component (7%, likely) in the SS 30s condition when compared to the control condition. The SS 120s condition showed greater ROM than the control condition following the SS intervention (l2%, likely) and DS/DA component (14%, likely). There were no other meaningful differences between conditions. (Table 22 and 24)

Quadriceps Force:

The SS 120s condition demonstrated decreases in quadriceps force following the **SS** intervention (-7.2%, likely) and **10-minute** rest period (-6.1%, likely) when compared to the pre-test. There were no meaningful changes in force production within the control, SS 30 and 60s conditions. (Table 4)

Quadriceps F100:

There were decreases in quadriceps F100 following the SS intervention in the SS 120s condition (29.6%, likely) when compared to the pre-test. The control, SS 30 and 60s showed no meaningful decreases in F100 force production.

Vertical Jump:

There were increases in vertical jump performance following the SS interventions in the control (6.2%, almost certain), SS 60s (4.6%almost certain) and SS 30s (3.3%, almost certain) conditions. Whereas, there was a disfacilitation of vertical jump enhancement the SS intervention in the SS 120s condition. The DS/DA component increased vertical jump performance in all conditions when compared to all SS intervention jump performance (**SS 120s:** 5.4%, likely; **SS 30s:** 5.2%, almost certain; **SS 60s:** 3.2%, likely and **Control:** 3%, likely). Following the ten-minute rest component vertical jump performance remained higher than the pre-test in all conditions; **Control** (6.9%, very likely), **SS 30s** (6.9%, almost certain), **SS 60s** (6.3%, very likely) and **SS 120s** (3.3%, likely). The control condition generated the best overall vertical jump performance when compared to all other conditions. (Table 6)

Evoked Twitch Force:

There were decreases in evoked twitch forces following the SS intervention in all conditions when compared to the pre test. The largest decreases were in the **SS 120s** (-26.1%, almost certain), followed by **SS 60s** (-18.3%, likely), **SS 30s** (-14.5%, likely) and **Control** (-11%, likely) conditions. The inclusion of DS/DA component within the full warm-up protocol increased twitch amplitude but remained lower than pre-test values (**SS 30s:** 6.3%, **SS 60s:** 4.7%, **SS 120s:** 4%, and **Control:** 3.2%). Ten-minutes rest component twitch amplitude remained lower in all conditions in comparison to the pre-test (**SS 120s:** 19.6%, almost certain; **SS 60s:** 18%, likely; **SS 30s:** 17.3%, almost certain and **Control:** 7.5%, likely). (Table 11)

ITT voluntary activation (VA%):

There were decreases in VA% following the DS/DA (28.4%, likely) component and 10-minute rest period (29.7%, likely) in the SS 30s condition when compared to the pre-test. There were also decreases in VA% following the DS/DA (24%, likely) component in the SS 60s condition when compared to the pre-test. Lastly, the10-minute rest period in the SS 120s condition showed decreased (21.1%, likely) VA%. (Table 12)

Electromechanical Delay (EMD):

There were decreases in the EMD following the DS/DA component in the control (11.1%, likely) and SS 120s (4.7%, likely) conditions when compared to the pre-test. There were increases in the EMD following the SS intervention in the SS 30s (-6%, likely, SS 60s (-7.3%, likely) and SS 120s (-11.7%, very likely) conditions when compared to the pre-test. There were no additional meaningful differences. (Table 15)

3.5 Discussion

The purpose of the study was to determine an effective full warm-up protocol with the inclusion of differing durations of SS, with an aerobic and DS/DA component on subsequent performance measures. The results demonstrated that various durations of SS, particularly longer durations (SS 120 and 60s) within a full warm-up protocol could impair but also improve various performance measures such as ROM and vertical jump height. The inclusion of a DS/DA component following SS may alleviate some of the SS-induced impairments and even enhance subsequent performance. The most important findings were as follows: a) meaningful decreases in quadriceps force production in the

SS 120s condition after the SS intervention and 10-minute rest period, b) decrease in quadriceps F100 force production following the SS intervention in the SS 120s condition, and c) additional meaningful increases in ROM with the SS 120 and 60s conditions for the hamstrings and quadriceps.

For quadriceps MVC force and F100, a substantial body of research shows that prolonged SS can impair subsequent performance in physiological strength measures such as MVC's (Behm et al., 2001, 2004, 2006, 2016; Behm & Chaouachi, 2011; Kay & Blazevich, 2012). In the current study, there were meaningful decreases in quadriceps force production in SS 120s condition following the SS intervention and 10-minute rest period as well as a meaningful decrease in quadriceps F100 in the SS 120s condition following the SS intervention. This finding is consistent with previously conducted research (Behm et al., 2016; Behm & Chaouachi, 2011; Kay & Blazevich, 2012). In accordance with the aforementioned reviews, the current study showed that a moderate duration of SS (≥60s per muscle group) could result in meaningful decreases in quadriceps isometric force and F100 production. It is possible that the SS interventions could have altered the viscoelastic properties (Ryan et al., 2008; Morse et al., 2008a), length tension relationship and deformation of the connective tissue such that the force producing capabilities of the MTU were limited (Power et al., 2004; Fowles, 2000). Additionally, the SS interventions used in the current study may have decreased neuromuscular activation. It has been suggested that the decrease in excitation of the motor neuron pool following SS can result from a decreased excitatory drive from the 1a afferents onto the alpha motor neuron. This neural inhibition could be attributed to decreased resting discharge rates of the muscle spindles (Avela et al., 1999).

The DS/DA component helped attenuate the SS-induced impairments in quadriceps MVC force and F100. In a review paper by Behm and Chaouachi (2011) it was stated that if a moderate volume (30-60s) of SS is performed prior to DS, then SS had a limited impact on subsequent performance. This is in accordance with research by Gelen (2010) and Chaouachi et al. (2008) who found no impairments in performance when pairing SS with a DS component. Although DS/DA can help decrease potential SS-induced decrements in performance, it has been found that combining DS/DA with SS (Wallman et al., 2008; Winchester et., al 2008) and or using an aerobic warm-up prior to SS (Behm et al., 2001, Behm & Kibele, 2007) can still decrease performance if the SS duration is prolonged.

In contrast to the meaningful improvements with the control, SS 30 and SS 60s conditions following the SS intervention, there was a disfacilitation of vertical jump height performance with the SS 120s condition following the SS intervention. This finding is in accordance with previously conducted research (Bradely et al., 2007; Wallman et al., 2005; Fletcher & Monte-Colombo, 2010). In contrast, some studies have incorporated SS and found no impairments in vertical jump height (Power et al., 2004; Behm et al., 2006). It was hypothesized that longer durations of SS further decrease MTU stiffness and increase compliance (Magnusson et al., 1998). In the current study, it is believed that 120s of SS may have altered the MTU stiffness leading to a decreased ability to transfer energy from the stretch shortening cycle (Cornwall et al., 2002). As mentioned previously, the 120s of SS adversely affected muscle activation and could also have played a role in limiting vertical jump height performance after the SS warm-up component.

The literature has conflicting evidence regarding the effect of dynamic activities on vertical jump performance; some studies show a significant increase (Hough et al., 2009; Thompson et al., 2007) while others report no effect (Bradley et al., 2007) following a DS/DA component. The current study found a meaningful increase in vertical jump performance following DS/DA when compared to SS. One explanation for the increase in jump performance is the increased neural excitation through dynamic changes in the length of the spindles thus activating Ia afferents leading to reflex-induced excitation of the alpha motor neuron (Avela et al., 1999; Behm et al., 2006). Additionally, the DS/DA component could have promoted changes in body temperature by increasing core and or muscle temperature allowing an enhanced neural conduction velocity and alteration of the visco-elasticity and decreasing resistance to movement (Young & Behm, 2003). There is also a possibility that DS/DA component increased post-activation potentiation (PAP) (Fletcher & Jones, 2004). Increased PAP following a DS and DA have been shown to increase phosphorylation of myosin regulatory light chains (Moore et al., 2008) and Ca 2+ release from the sarcoplasmic reticulum (Allen et al., 1989) thus increasing the rate of cross bridge formation and overall force production (Yamaguchi & Ishii, 2005, Houston & Grange, 1990). It is thought that the DS/DA component in the current study helped increase PAP and neural excitation therefore increasing subsequent performance when compared to performance following SS.

Typically, SS-induced increases in ROM have been attributed to a reduced MTU stiffness, which allows for less resistance and force to stretch the muscle in a relaxed state (Young et al., 2003). SS-induced increases in ROM could also be credited to an improved stretch tolerance of the pain associated with prolonged and high intensity SS (Magnusson et al., 1998). Further increases in ROM with DS compared to SS can be attributed to an elevated muscle and body temperature (Fletcher and Jones, 2004) or decreased inhibition of the antagonist muscle (Jaggers et al., 2008; Yamaguchi & Ishii, 2005).

Evoked twitch force represents the excitation contraction coupling process (Behm et al., 2004). In all conditions, there were meaningful decreases in the evoked twitch forces following SS and DS/DA component and 10-minute rest period. The decrease in twitch forces may be attributed to possible fatigue experienced when completing the full warm-up protocol and performance tests. Previous research has shown decreases in evoked twitches with sustained (Grange et al., 1991), and intermittent maximal contractions (Bigland-Ritchie, et al., 1983). Additional to fatigue, it has been shown that SS can decrease twitch forces by approximately 6-18% (Avela et al., 2004; Behm et al., 2001; Ce et al., 2008; Fowles et al., 2000; Ryan et al., 2008). In contrast to the previously mentioned research, Herda et al. (2008) found no changes in evoked twitch force following 20- minutes of passive stretching whereas Behm et al. (2001) showed a SS-induced decrease in evoked twitch force. The prolonged durations of SS caused larger impairments in evoked twitch forces when compared to the control condition.

There were meaningful decreases in VA% following DS/DA component in the SS 30 and 60s condition. Additionally, there were meaningful decreases in VA% following 10-minute rest after the warm-up in the SS 30 and 120s conditions. There were no changes in VA% throughout the control condition, indicating that any duration of SS along with DS/DA may have increased MTU compliance causing disfacilitation of muscle spindle-induced excitation. Researchers have previously reported decreases in VA% following various SS interventions (Fowles et al., 2000 and Behm, 2001).

However, a SS-induced decrease in VA% is not always evident (Power et al., 2004). It is possible that the decreased VA% can arise from inhibition of spinal motoneurons. Motoneuron inhibition can arise from peripheral sources such as chemical stimuli that excite chemosensitive afferents (groups III and IV), which are nociceptive (Garland & Kaufman, 1995). Metabolites have the ability to reduce mechanical thresholds of group III and IV afferents (Loring & Hershenson, 1992) therefore impacting central nervous system activation (Gandevia, 1998).

The EMD is defined as the time it takes from the onset of electrical activation of the muscle to the initial production of force (Conforto et al., 2006, Hopkins et al., 2007). There are several factors that contribute to an EMD such as the duration of the excitation contraction coupling, the elongation of the series elastic component and the time course for the propagation of the action potential to occur (Grosset et al., 2009). In the current study there was a meaningful increase in EMD duration (slower onset of force) following the SS interventions in the SS 30, 60 and 120s conditions. Additionally, there were meaningful decreases in EMD (faster onset of force) following the DS/DA component in the control and SS 120s conditions. This finding is consistent with previous research by Ryan et al (2009) who incorporated 20-minutes of passive stretching and showed an increased EMD. The increased EMD was attributed to SS-induced elongation of the MTU resulting in a less stiff series elastic component and transfer of force from the contractile components to the bone. This finding is also in concurrence with research conducted by Kubo et al. (2001) and Ryan et al. (2008) who demonstrated transient decreases in MTU stiffness after various stretching interventions. Therefore, it is possible that stretching created more “slack” and increased compliance in the MTU, which increased the time for force production (Costa et al., 2010). The EMD results in the current study argue against the previous rationale postulated for the decreased VA% via increased MTU compliance. A faster EMD following the DS component suggests that the tissue was stiffer and less complaint. Therefore, there could be additional factors related to changes in EMD and VA% such as reduced muscle spindle firing frequency due to accommodation or habituation. Additionally, it is known that motoneurons intrinsically slow their firing rate after extended activation (late adaptation) (Gardiner, 2001). Thus, the changes in EMD and VA% following SS and DS in the current study may arise from changes in MTU stiffness, increased MTU compliance, late adaptation and reduced muscle spindle firing frequencies due to accommodation. Important to mention is that EMD decreased in only two conditions (control and SS 120s) following the DS component, we do not have a reasonable explanation for this anomaly.

Delimitations:

A limitation in the current study was the sample population. All subjects were resistance and endurance trained for a minimum of 2 years with an athletic background but were not elite athletes. In the future, when conducting research that is more applicable to elite athletes, the inclusion criteria should consist of subjects who are currently involved in highly competitive sports. Additionally, only males were used as participants in the current study, therefore in the future, similar research must be conducted with female participants. Lastly, the age range of participants was 20-29 years of age. Therefore, using a variety of age groups and the effects of various warm-up protocols on performance measures should be analyzed.

3.6 Conclusions:

This is one of few studies that incorporate a full warm-up protocol including the three traditional components of a warm-up routine: an aerobic component, differing SS interventions and a DS/DA component (Behm & Chaouachi. 2011). The decrements in subsequent performance following prolonged SS were attributed to increases in MTU compliance, decreases in MTU stiffness and fatigue experienced while completing the full warm-up protocol. All conditions provided increases in ROM that continued to increase as participants completed each of the three warm-up interventions. Additionally, this study provides strong evidence that a DS/DA component can further increase ROM, regardless of the duration of SS. When performing high intensity testing measures or contractions such as maximum force production, rate of force development (F100) and vertical jumps, then prolonged SS can decrease subsequent performance. It is necessary that additional research is conducted investigating specific full warm-up protocols relevant to different sports and positions within a sport to develop guidelines ensuring there are no impairments in performance due to the warm-up routine an athlete partakes in.

Acknowledgments

We would like to acknowledge the contributions of Dr. Thamir Alkanani for his organization and preparation of the laboratory and equipment. The authors declare that the results of the study are presented clearly, honestly and without fabrication, falsification, or inappropriate data manipulation.

Conflict of Interest

There were no conflicts of interest of the authors with the information obtained within the manuscript.

3.7 References:

Allen, D. G., Lee, J. A., & Westerblad, H. (1989). Intracellular calcium and tension during fatigue in isolated single muscle fibres from Xenopus laevis. *J. Physiol*, *415*(1), 433-458.

Avela, J., Kyröläinen, H., & Komi, P. V. (1999). Altered reflex sensitivity after repeated and prolonged passive muscle stretching. *J. Appl. Physiol*, *86*(4), 1283-1291.

Avela, J., Finni, T., Liikavainio, T., Niemelä, E., & Komi, P. V. (2004). Neural and mechanical responses of the triceps surae muscle group after 1 h of repeated fast passive stretches. *J. Appl. Physiol*, *96*(6), 2325-2332.

Bacurau, R. F. P., Monteiro, G. A., Ugrinowitsch, C., Tricoli, V., Cabral, L. F., & Aoki, M. S. (2009). Acute effect of a ballistic and a static stretching exercise bout on flexibility and maximal strength. *J. Strength Cond. Res, 23*(1), 304-308.

Beckett, J.R.J., Schneiker, K.T., Wallman, K.E., Dawson, B.T. and Guelfi, K.J. (2009). Effects of static stretching on repeated sprint and change of direction performance. *Med. Sci. Sports Exerc*, 41: 444-50.

Behm D.G. (2009). The interpolated twitch technique may be valid and reliable but limited. *J. Appl. Physiol,* 107 (1): 362.

Behm, D. G., Anderson, K., & Curnew, R. S. (2002). Muscle force and activation under stable and unstable conditions. *J. Strength Cond. Res*, *16*(3), 416-422.

Behm D.G., St-Pierre D.M.M., & Perez D. (1996). Muscle Inactivation: An Assessment of the Interpolated Twitch Technique. *J. Appl. Physiol,* 81(5): 2267-2273.

Behm D.G., Whittle J., Button D., & Power K. (2002). Intermuscle differences in activation. *Muscle and Nerve,* 25: 236-243.

Behm D.G., Power K., White M.D., LeDez K., Decker D., & Drinkwater E. (2003). Effects of Hyperbaric Pressure on Voluntary and Evoked Skeletal Muscle Contractile Properties. *Undersea and Hyperb. Med.,* 30(2): 103-115.

Behm, D. G., Chaouachi, A. (2011). A review of the acute effects of static and dynamic stretching on performance. *Euro. J. Appl. Physiol*, 111(11), 2633-2651.

Behm, D. G., & Anderson, K. G. (2006). The role of instability with resistance training. *J. Strength Cond. Res*, *20*(3), 716.

Behm, D.G., Blazevich, A.D., Kay, A.J., & McHugh, M. (2016). Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Appl Physiol Nutr Metab,* 41: 1-11.

Behm, D. G., Bambury, A., Cahill, F., & Power, K. (2004). Effect of acute static stretching on force, balance, reaction time, and movement time. *Med. Sci. Sports Exerc.,* 36, 1397-1402.

Behm, D. G., & Kibele, A. (2007). Effects of differing intensities of static stretching on jump performance. *Eur. J. Appl. Physiol,.* 101(5), 587-594.

Behm, D. G., Button, D. C., & Butt, J. C. (2001). Factors affecting force loss with prolonged stretching. *Can. J. Appl. Physiol.,* 26(3), 262-272.

Bigland- Ritchie, B., R. Johansson, O.C.J. Lippoid & J.J. Woods. (1983). Contractile speed and EMG changes during fatigue or sustained maximal voluntary contractions. *J. Neurophysiol.,* 50:313- 324.

Bradley, P. S., Olsen, P. D., & Portas, M. D. (2007). The effect of static, ballistic, and proprioceptive neuromuscular facilitation stretching on vertical jump performance. *J. Strength Cond. Res.,* 21(1), 223-226.

Button, D. C., & Behm, D. G. (2008). The effect of stimulus anticipation on the interpolated twitch technique. *J. Sports Med.*, *7*(4), 520.

Cè, E., Margonato, V., Casasco, M., & Veicsteinas, A. (2008). Effects of stretching on maximal anaerobic power: the roles of active and passive warm-ups. *J. Strength Cond. Res* 22(3), 794-800.

Chaouachi, A., Castagna, C., Chtara, M., Brughelli, M., Turki, O., Galy, O., Chamari, K., and Behm, D.G. (2010). Effect of Warm-Ups Involving Static or Dynamic Stretching on Agility, Sprinting, and Jumping Performance in Trained Individuals. *J. Strength Cond. Res.,*24: 2001-2011.

Chaouachi, A., Chamari, K., Wong, P., Castagna, C., Chaouachi, M., Moussa-Chamari, I., & Behm, D. G. (2008). Stretch and sprint training reduces stretch-induced sprint performance deficits in 13-to 15-year-old youth. *Eur. J. Appl. Physiol.*, *104*(3), 515.

Cohen J. (1988). Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Conforto, S., Mathieu, P., Schmid., M., Bibbo, D., Florestal, J., & D'Alessio, T,. (2006). How much can we trust the electromechanical delay estimated by using electromyography? *Eng. Med. Biol. Soc.,* pp 1256–1259.

Cornwell, A., Nelson, A., Sidaway, B,. (2002). Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. *Eur J Appl Physiol.,* 86:428–434.

Costa, Pablo B., et al. (2010). Acute effects of passive stretching on the electromechanical delay and evoked twitch properties. *Eur. J. Appl. Physiol.,* 108.2 (2010): 301

Drinkwater E.J., & Behm D.G. (2007). Effects Of 22C Muscle Temperature On Voluntary And Evoked Muscle Properties During And After High Intensity Exercise. *Appl. Physiol. Nutr. Metab*., 32: 1043-1051

Ebben, W. P., & Blackard, D. O. (2001). Strength and conditioning practices of National Football League strength and conditioning coaches. *J. Strength Cond. Res.,15*(1), 48-58.

Ebben, W. P., Carroll, R. M., & Simenz, C. J. (2004). Strength and conditioning practices of National Hockey League strength and conditioning coaches. *J. Strength Cond. Res.*, *18*(4), 889-897.

Ebben, W. P., Hintz, M. J., & Simenz, C. J. (2005). Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *J. Strength Cond. Res.*, *19*(3), 538-546.

Fletcher, I. M., & Anness, R. (2007). The acute effects of combined static and dynamic stretch protocols on fifty-meter sprint performance in track-and-field athletes. *J. Strength Cond. Res*., *21*(3), 784-787.

Fletcher, I. M., & Jones, B. (2004). The effect of different warm-up stretch protocols on 20 meter sprint performance in trained rugby union players. *J. Strength Cond. Res.* 18(4), 885-888.

Fletcher, I.M., & Monte-Colombo, M.M. (2010). An investigation into the possible physiological mechanisms associated with changes in performance related to acute responses to different preactivity stretch modalities. *Appl. Physiol. Nutr. Metab*., 35: 27-34.

Fowles, J. R., Sale, D. G., & MacDougall, J. D. (2000). Reduced strength after passive stretch of the human plantarflexors. *J. Appl. Physiol.,* 89(3), 1179-1188.

Gandevia, S. C. (1998). Neural control in human muscle fatigue: changes in muscle afferents, moto neurones and moto cortical drive. *Acta Physiologica*, *162*(3), 275-283.

Gardiner, P.F. (2001). Neuromuscular Aspects of Physical Activity. Windsor, ON: Human Kinetics Canada.

Garland, S. J., & Kaufman, M. P. (1995). Role of muscle afferents in the inhibition of motoneurons during fatigue. In *Fatigue* (pp. 271-278). Springer US.

Grange, R.W. and M.E. Houston. (1991). Simultaneous potentiation and fatigue in quadriceps after 60-second maximal voluntary isometric contraction. *J. Appl Physiol.*, 70:726-731.

Gelen, E. (2010). Acute effects of different warm-up methods on sprint, slalom dribbling, and penalty kick performance in soccer players. *J. Strength Cond. Res.*, 24(4), 950-956.

Grabow, L, Young, JD, Alcock, LR, Quigley, PJ, Byrne, JM, Granacher, U, Škarabot, J and Behm, D.G. (2017). Higher quadriceps roller massage forces do not amplify range- of-motion-increases or impair strength and jump performance. *J. Strength Cond. Res.,* In Press.

Gleim, G. W., & McHugh, M. P. (1997). Flexibility and its effects on sports injury and performance. *Sports medicine*, *24*(5), 289-299.

Grosset, J.F., Piscione, J., Lambertz, D., & Perot, C. (2009). Paired changes in electromechanical delay and musculo-tendinous stiVness after endurance or plyometric training. *Eur. J. Appl. Physiol.,* 105:131– 139.

Halperin, I., Copithorne, D., & Behm, D.G. (2014). Unilateral isometric muscle fatigue decreases force production and activation of contralateral knee extensors but not elbow flexors. *Appl. Physiol. Nutr. Metab.,* 39: 1-7.

Herda, T. J., Cramer, J. T., Ryan, E. D., McHugh, M. P., & Stout, J. R. (2008). Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *J. Strength Cond. Res*., 22(3), 809-817.

Hodgson, D.D., Quigley, P.J., Whitten, J.H.D., Reid,J.C., & Behm, D.G. (submitted for Publication). (2017). Roller massage applied at ten-minute intervals prolongs active range of motion improvements up to 30-minutes without impairing performance. *J. Strength Cond. Res.*

Holt, B. & Lambourne, K. (2008). The Impact of Different Warm-Up Protocols on Vertical Jump Performance in Male Collegiate Athletes. . *J. Strength Cond. Res*., 1: 226-229.

Hopkins, J.T., Feland, J.B., Hunter, I. (2007). A comparison of voluntary and involuntary measures of electromechanical delay. *Int J Neurosci*., 117:597–604.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc., 41*(1), 3.

Hough, P.A., Ross, E.Z., and Howatson, G. (2009). Effects of dynamic and static stretching on vertical jump performance and electromyographic activity. *J. Strength Cond. Res.,* 23: 507-512.

Hopkins, W. G. (2004). How to interpret changes in an athletic performance test. *Sportscience*, *8*(1), 1-7.

Houston, M. E., & Grange, R. W. (1990). Myosin phosphorylation, twitch potentiation, and fatigue in human skeletal muscle. *Can. J. Appl. Physiol., 68*(7), 908-913.

Jaggers, J. R., Swank, A. M., Frost, K. L., & Lee, C. D. (2008). The acute effects of dynamic and ballistic stretching on vertical jump height, force, and power. *J. Strength Cond. Res.,* 22(6), 1844-1849.

Johar, P., Grover, V., Topp, R., Behm, D. (2012). A comparison of topical menthol to ice on pain, evoked tetanic and voluntary force during delayed onset muscle soreness. *Int. J. Sports Phys. Ther.,*7(3): 314-322.

Kawamoto, J.E., Aboodarda, *S.J.,* Behm, D.G. (2014). Effect of differing intensities of fatiguing dynamic contractions on contralateral homologous muscle performance. *J. Sports Sci. Med.,* 13: 836-845.

Kay, A. D., & Blazevich, A. J. (2012). Effect of acute static stretch on maximal muscle performance: a systematic review. *Medicine & Science in Sports & Exercise*, *44*(1), 154-164.

Kistler, B.M., Walsh, M.S., Horn, T.S. & Cox, R.H. (2010). The acute effects of static stretching on the sprint performance of collegiate men in the 60- and 100-m dash after a dynamic warm-up. *J. Strength Cond. Res*. 24:2280-4.

Kubo, K., Kanehisa, H., & Y, Fukunaga, T. (2001). Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *J Appl Physiol.,* 90:520–527.

Little, T., Williams, A.G. (2006) Effects of differential stretching protocols during warm-ups on high-speed motor capacities in professional soccer players. *J. Strength Cond. Res.,* 20:203–207.

Loring, S. H., & Hershenson, M. B. (1992). Effects of series compliance on twitches superimposed on voluntary contractions. *J. Appl. Physiol.*, *73*(2), 516-521.

Ludbrook, J., & Dudley, H. (1998). Why permutation tests are superior to t and F tests in biomedical research. *The American Statistician*, *52*(2), 127-132.

MacDonald, G. Z., Penney, M. D., Mullaley, M. E., Cuconato, A. L., Drake, C. D., Behm, D. G., & Button, D. C. (2013). An acute bout of self-myofascial release increases range of motion without a subsequent decrease in muscle activation or force. *J. Strength Cond. Res.,* 27(3), 812-821.

Magnusson, S. P., Aagard, P., Simonsen, E., & Bojsen-Møller, F. (1998). A biomechanical evaluation of cyclic and static stretch in human skeletal muscle. *Int. J. Sports. Med., 19*(05), 310-316.

Manoel, M.E., Harris-Love, M.O., Danoff, J.V., & Miller, T.A. (2008). Acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on muscle power in women. *J. Strength Cond. Res.,* 22:1528–1534.

Mesin, L., Merletti, R., & Rainoldi, A. (2009). Surface EMG: The issue of electrode location. J. Electromyogr. Kinesiol., 19: 719–726.

Moore, D. R., Burgomaster, K. A., Schofield, L. M., Gibala, M. J., Sale, D. G., & Phillips, S. M. (2004). Neuromuscular adaptations in human muscle following low intensity resistance training with vascular occlusion. *Eur. J. Appl. Physiol.*, *92*(4-5), 399-406.

Morse, C. I., Degens, H., Seynnes, O. R., Maganaris, C. N., & Jones, D. A. (2008a). The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. *J Physiol*, *586*(1), 97-106.

Murphy J.R. DiSanto M.C., Alkanani T., Behm D.G. (2010). Aerobic Activity Before and Following Short Duration Static Stretching Improves Range of Motion and Performance versus a Traditional Warm-up. *Appl. Physiol. Nutr. Metab.* 35: 679-690.

Nelson, A. G., & Kokkonen, J. (2001). Acute ballistic muscle stretching inhibits maximal strength performance. *Res. Q. Exer. Sport.,* 72(4), 415-419.

Paradisis, G. P., Pappas, P. T., Theodorou, A. S., Zacharogiannis, E. G., Skordilis, E. K., & Smirniotou, A. S. (2014). Effects of static and dynamic stretching on sprint and jump performance in boys and girls. *J. Strength Cond. Res*., *28*(1), 154-160.

Pearce AJ, Kidgell DJ, Zois J, Carlson JS (2009) Effects of secondary warm up following stretching. *Eur. J. Appl. Physiol.,* 105:175–183.

Power, K, Behm, D, Farrell, C, Carroll, M, and Young, W.(2004). An acute bout of static stretching: effects on force and jumping performance. *Med. Sci. Sports Exerc.,* 36: 1389-1396.

Ryan, E. D., Beck, T. W., Herda, T. J., Hull, H. R., Hartman, M. J., Costa, P. B., & Cramer, J. T. (2008). The time course of musculotendinous stiffness responses following different durations of passive stretching. *J. Orthop. Sports. Phys. Ther., 38*(10), 632-639.

Ryan, E. D., Herda, T. J., Costa, P. B., Defreitas, J. M., Beck, T. W., Stout, J., & Cramer, J. T. (2009). Determining the minimum number of passive stretches necessary to alter musculotendinous stiffness. *Journal of sports sciences*, *27*(9), 957-961.

Šambaher, N., *Aboodarda, S,J.,* Button, D.C., Behm, D.G. (2016). The effect of an ankle compression garment on fatigue and performance. *J. Strength Cond. Res*., 30(2): 326-335.

Samuel, M. N., Holcomb, W. R., Guadagnoli, M. A., Rubley, M. D., & Wallmann, H. (2008). Acute effects of static and ballistic stretching on measures of strength and power. *J. Strength Cond. Res*., 22(5), 1422-1428.

Samson, M., Button, D. C., Chaouachi, A., & Behm, D. G. (2012). Effects of dynamic and static stretching within general and activity specific warm-up protocols. *J. Sports Sci. Med.*, *11*(2), 279.

Sekir, U., Arabaci, R., Akova, B., & Kadagan, S.M. (2009) Acute effects of static and dynamic stretching on leg flexor and extensor isokinetic strength in elite women athletes. *Scand. J. Med. Sci. Sports,* 20(2), 268- 281.

Simenz, C. J., Dugan, C. A., & Ebben, W. P. (2005). Strength and conditioning practices of National Basketball Association strength and conditioning coaches. *J. Strength Cond. Res*., *19*(3), 495-504.

Thompsen, A. G., Kackley, T., Palumbo, M. A., & Faigenbaum, A. D. (2007). Acute effects of different warm-up protocols with and without a weighted vest on jumping performance in athletic women *J. Strength Cond. Res*., *21*(1), 52.

Torres, E. M., Kraemer, W. J., Vingren, J. L., Volek, J. S., Hatfield, D. L., Spiering, B. A., & Häkkinen, K. (2008). Effects of stretching on upper-body muscular performance. *J. Strength Cond. Res*., 22(4), 1279-1285.

Unick, J., Kieffer, H. S., Cheesman, W., & Feeney, A. (2005). The acute effects of static and ballistic stretching on vertical jump performance in trained women. *J. Strength Cond. Res.,* 19(1), 206-212.

Vetter, R.E. (2007). Effects of six warm-up protocols on sprint and jump performance. *J.Strength.Cond.Res*., 21: 819-823.

Wallmann, H.W., Mercer, J.A. & McWhorter, J.W. 2005. Surface electromyographic assessment of the effects of static stretching of the gastrocnemius on vertical jump performance. *J. Strength Cond. Res.* 19: 684-8.

Wallmann, H. W., Mercer, J. A., & Landers, M. R. (2008). Surface electromyographic assessment of the effect of dynamic activity and dynamic activity with static stretching of the gastrocnemius on vertical jump performance. *J. Strength Cond. Res.,22*(3), 787-793.

Winchester, J. B., Nelson, A. G., Landin, D., Young, M. A., & Schexnayder, I. C. (2008). Static stretching impairs sprint performance in collegiate track and field athletes. *J. Strength Cond Res., 22*(1), 13-19.

Yamaguchi, T., & Ishii, K. (2005). Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. *J. Strength Cond Res.,* 19(3), 677-683.

Young, W., & Behm, D.G. (2003). "Effects of running, static stretching and practice jumps on explosive force production and jumping performance." *J. Sports Med. Phys. Fit.,* 43.1: 21.

3.8 Tables and figures

Figure 1. Experimental Design. Acronyms: MVIC maximum voluntary isometric contraction, ROM range of motion

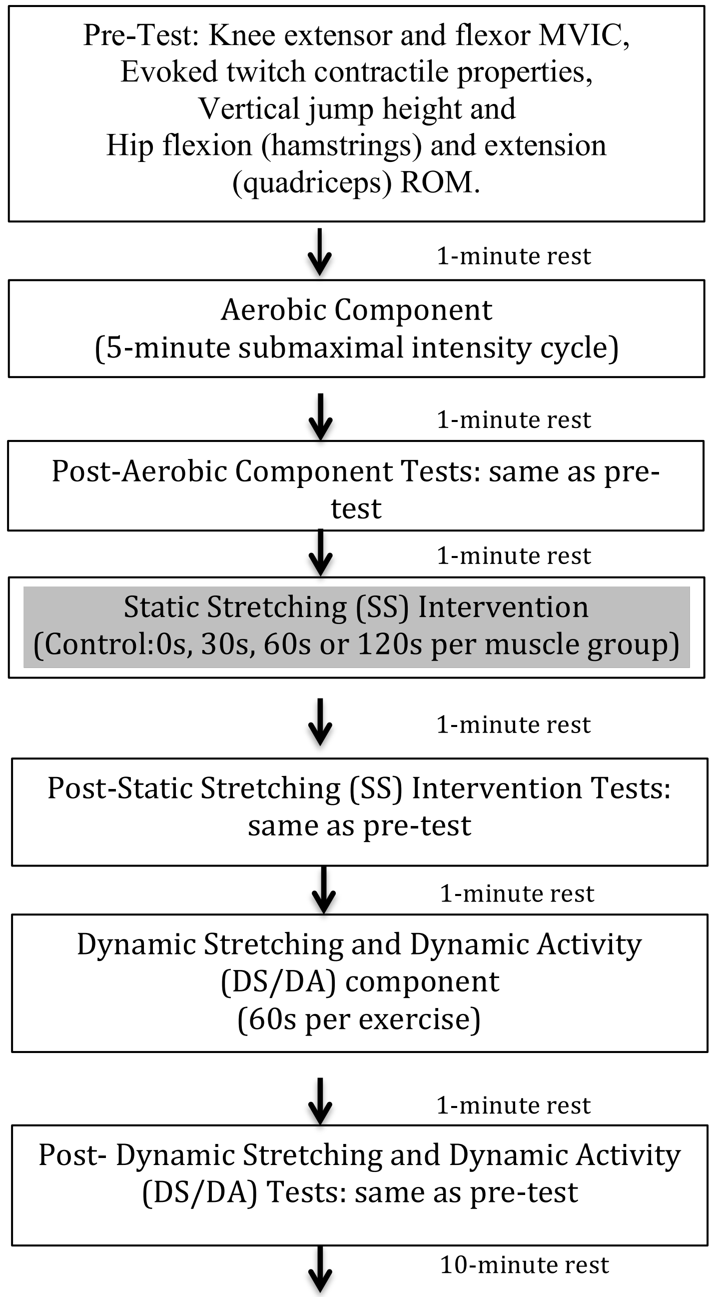

Table 1. ICC Reliability measures for performance and physiological measures

Performance and Physiological Measures	**ICC Reliability**
Hamstrings and Quadriceps ROM	0.899/ 0.888
Hamstrings and Quadriceps MVC Force	0.769/ 0.904
Hamstrings and Quadriceps F100	0.894/ 0.779
Vertical Jump	0.961
Evoked Twitch Force	0.750
Quadriceps and Hamstrings EMG	0.712/ 0.750
ITT VA% (Voluntary Activation)	0.835
Electromechanical Delay (EMD)	0.900

Table 2. Hip flexion (hamstrings) range of motion (ROM) performance (degrees). Shaded cells indicate increased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hip flexion ROM (Degrees)	Pre-test vs. Post-Aerobic Warm-up component	Pre- vs. Post-SS intervention	Pre- vs. Post- DS/DA component	Pre- vs. 10-minute rest period
Control Mean pre= 88.87	ES=0.4 (S) % Likelihood= 98.4 Mean= 92.93 95% CI= 2.4-5.7 % Change= 4.4	ES=0.6 (M) % Likelihood= 99.6 Mean= 95.3 95% CI= 3.5-9.3 % Change=7.8	ES= 0.9 (L) % Likelihood= 99.9 Mean= 98.3 95% CI = 6.2-12.7 % Change=10.6	ES= 0.8 (L) % Likelihood= 99.2 Mean= 97.6 95% CI= 5.1-12.4 % Change= 9
SS 30s Mean pre= 91.5	ES= 0.2 (S) % Likelihood= 75.0 Mean=94 95% CI= 0.9-3.9 % Change= 3.6	ES= 0.4 (S) % Likelihood= 98.4 Mean= 95.29% CI= -2.2- 5.5 % Change= 4.9	ES= 1.0 (L) % Likelihood= 99.9 Mean= 101.7 95% CI= 7.8-12.8 % Change=11.1	ES= 0.7 (M) % Likelihood= 99.9 Mean= 99.1 95% CI= 4.5-10.6 % Change= 8.7
SS 60s Mean pre= 88.5	ES=0.3 (S) % Likelihood= 84.2 Mean= 91.7 95% CI= 1.8-4.2 % Change= 4.3	ES= 0.6 (M) % Likelihood= 99.8 Mean= 96.1 95% CI= 5.3-10.2 % Change=8.1	ES= 1.0 (L) % Likelihood= 99.9 Mean= 98.6 95% CI = 7.3-12.8 % Change=11.4	ES= 0.7 (M) % Likelihood= 99.9 Mean= 97.1 95% CI = 6.5-11.2 % Change=10.1
SS 120s Mean pre= 89.2	ES= 0.5 (M) % Likelihood= 99.9 Mean= 93.4 95% CI= 2.8-5.5 % Change= 5.6	ES= 1.0 (L) % Likelihood= 99.9 Mean= 98 95% CI= 6.5-11.4 % Change=9.2	ES= 1.3 (L) % Likelihood= 99.9 Mean= 100.1 95% CI= 9.2-14.3 % Change=11.7	ES= 1.2 (L) % Likelihood= 99.9 Mean= 99.9 95% CI= 8.4-13.4 % Change=11.1

Table 3. Between condition comparisons. Shaded cells indicate increased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

	SS Condition	**DS/DA Condition**	**10-minute Condition**
Hip flexion (Hamstrings) ROM			
Control vs. SS 120s Intervention	ES= 0.3 (S) % Likelihood= 79 95% CI= -0.4-8.4	ES= 0.3 (S) % Likelihood= 75 95% CI= -0.9-8.4	ES= 0.1 (T) % Likelihood= 71 95% CI= -3.7-13.1
Hip extension (Quadriceps) ROM			
Control vs. SS 30s Intervention	ES= 0.2 (S) % Likelihood= 48.7 95% CI= -6.0-2.0	ES= 0.3 (S) % Likelihood= 75 95% CI= -7.5-0.7	ES= 0.1 (T) % Likelihood= 48.2 95% CI= -5.8-1.6
Hip Flexion (Quadriceps) ROM			
Control vs. SS 120s Intervention	ES= 0.4 (S) % Likelihood= 78.5 95% CI= -7.8-0.6	ES= 0.5 (M) % Likelihood= 75 95% CI= -10-7.7	ES=-0.2 (S) % Likelihood= 55.4 95% CI= -7.1-2.1

Table 4. Hip Extension (Quadriceps) ROM performance (degrees). Shaded cells indicate increased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps ROM (Degrees)	**Pre-test vs. Post-Aerobic Warm-up component**	**Pre- vs. Post-SS intervention**	**Pre- vs. Post DS/DA component**	**Pre- vs. 10-minute rest period**
Control Mean pre= 49	ES= 0.3 (M) % Likelihood= 87.1 Mean= 45.9 95% CI=5.0-1.1 % Change= 6.3	ES= 0.5 (M) % Likelihood= 96.7 Mean= 43.6 95% CI- 9.0-1.7 % Change=11.1	ES= 0.6 (M) % Likelihood= 98.0 Mean= 42.8 95% CI=-10.1-2.2 % Change=12.7	ES= 0.8 (L) % Likelihood= 99.2 41.6 95% CI= 11.7-3.2 % Change=15.2
Static Stretching 30 seconds Mean pre= 48.1	ES= 0.4 (M) % Likelihood= 98.6 Mean=43.7 95% CI=-6.6-2.7 % Change= 9.3	ES= 0.5 (M) % Likelihood= 99.6 Mean= 41.6 95% CI=-9.2-3.7 % Change=13.6	ES= 0.7 (M) % Likelihood= 99.9 Mean= 39.2 95% CI=-11.7-5.8 % Change=18.2	ES= 0.7 (M) % Likelihood= 99.9 Mean= 39.5 95% CI=-11.7-5.7 % Change= 18
Static stretching 60 seconds Mean pre= 45.9	ES= 0.3 (S) % Likelihood= 93.6 Mean= 43 95% CI=-5.0-1.7 % Change= 7.2	ES= 0.5 (M) % Likelihood= 93.9 Mean= 41.3 95% CI=-8.8-1.1 % Change=10.8	ES= 0.7 (M) % Likelihood= 99.6 Mean= 39.3 95% CI=-10.6-3.5 % Change=15.6	ES= 0.5 (M) % Likelihood= 94.2 Mean= 41 95% CI=-9.6-1.1 % Change=11.5
Static Stretching of 120 sconds Mean pre= 44.8	ES= 0.3 (S) % Likelihood= 80.2 Mean= 42 95% CI=-4.5-1.3 % Change= 6.5	ES= 0.5 (M) % Likelihood= 99.9 Mean= 38.9 95% CI=-7.9-3.8 % Change=13.2	ES= 0.7 (M) % Likelihood= 99.9 Mean= 37.3 95% CI=-9.6-5.2 % Change=16.3	ES= 0.5 (M) % Likelihood= 99.9 Mean= 39.1 95% CI=-7.6-3.8 % Change=12.8

Table 5. Quadriceps MVIC force productions (Kg). Lightly shaded areas indicate a decrease in performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps MVC Force (kg)	**Pre-test vs. Post-Aerobic Warm-Up Component**	**Pre- vs. Post-SS Intervention**	**Pre- vs. Post DS/DA Component**	**Pre- vs. 10-minute Rest Period**
Control Mean pre= 59.6	ES= 0.1 (T) % Likelihood= 33.3=9 Mean= 61.7 95% CI=-0.5-4.6 % Change= 3.3	ES= 0.1 (T) % Likelihood= 28.8 Mean= 58 95% CI=-5.3-2.2 % Change= 2.4	ES= 0.01 (T) % Likelihood= 12.3 Mean= 58 95% CI=-4.1-4.5 % Change= 0.4	ES= 0.08 (T) % Likelihood= 24.6 Mean= 55 95% CI=-4.6-2.9 % Change= 1.5
Static Stretching 30 seconds Mean pre= 61.7	ES= 0.2 (T) % Likelihood= 46.2 Mean= 59.7 95% CI=-5.3-1.5 % Change= 3.2	ES= 0.06 (T) % Likelihood= 16.5 Mena= 61 95% CI=-3.6-2.4 % Change= 1.1	ES= 0.03 (T) % Likelihood= 17.37 Mean= 62 95% CI=-3.7-4.2 % Change= 0.5	ES= 0.2 (T) % Likelihood= 32.4 Mean= 60.7 95% CI=-6.1-4.0 % Change= 1.7
Static Stretching 60 seconds Mean pre= 57.1	ES= 0.08 (T) % Likelihood= 23.6 Mean= 56.1 95% CI=-5.4-3.5 % Change= 1.7	ES= 0.04 (T) % Likelihood= 24.7 Mean= 55.6 95% CI=-6.0-5.1 % Change= 0.9	ES= 0.1 (T) % Likelihood= 29.8 Mean= 56.1 95% CI=-5.3-2.9 % Change=2.1	ES= 0.1 (T) % Likelihood= 41.3 Mean= 58.7 95% CI=-4.9-8.3 % Change= 2.9
Static Stretching 120 seconds Mean pre= 64.2	ES= 0.2 (T) % Likelihood= 51.3 Mean= 61.4 95% CI=-5.8-0.27 % Change= 4.6	ES= 0.3 (S) % Likelihood= 93.1 Mean= 59.6 95% CI=-7.2 - -2.1 % Change= 7.2	ES= 0.1 (T) % Likelihood= 23.6 Mean= 62.4 95% CI=-4.5-1.1 % Change= 2.8	ES= 0.3 (S) % Likelihood= 75.0 Mean= 60.9 95% CI=-7.6- -0.2 % Change= 6.1

Table 6. **Table 6**. Vertical jump performance (inches). Shaded cells indicate increased performance. Lightly shaded cell indicates decreased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval.

Vertical Jump (cm)	**Pre-test vs. Post-Aerobic Warm-Up Component**	**Pre- vs. Post-SS Intervention**	**Pre- vs. Post DS/DA Component**	**Pre- vs. 10-minute Rest Period**
Control Mean pre= 48.7	ES= 0.4 (S) % Likelihood= 95.6 Mean= 51.1 95% CI= 0.5-1.2 % Change= 4.7	ES= 0.5 (M) % Likelihood= 99.9 Mean= 51.5 95% CI= 0.8-1.5 % Change= 6.2	ES= 0.8 (L) % Likelihood= 99.9 Mean= 53.6 95% CI=-1.4-2.5 % Change= 9.2	ES= 0.6 (M) % Likelihood= 98.9 Mean= 53.3 95% CI= 0.6-2.2 % Change= 6.9
Static Stretching 30 seconds Mean pre= 50.8	ES= 0.4 (S) % Likelihood= 98.9 Mean= 53.3 95% CI= 0.6-1.4 % Change= 4.8	ES= 0.2 (S) % Likelihood= 76.1 Mean= 52.3 95% CI= 0.1-1.2 % Change= 3.3	ES= 0.7 (M) % Likelihood= 99.9 Mean= 55.4 95% CI= 1.3-2.4 % Change= 8.5	ES= 0.6 (M) % Likelihood= 99.8 Mean= 54.4 95% CI= 0.9-2.1 % Change= 6.9
Static Stretching 60 seconds Mean pre= 50.8	ES= 0.3 (S) % Likelihood= 85.9 Mean= 52.8 95% CI=0.4-1.1 % Change= 3.8	ES= 0.3 (S) % Likelihood= 77% Mean= 53 95% CI= 0.09-1.4 % Change= 4.6	ES= 0.6 (M) % Likelihood= 99.9 Mean= 55.2 95% CI= 1.1-2.3 % Change= 7.8	ES= 0.5 (M) % Likelihood= 98.8 Mean= 54.1 95% CI= 0.7-1.9 % Change= 6.3
Static Stretching 120 seconds Mean pre= 52.3	ES= 0.3 (S) % Likelihood= 87.7 Mean pre= 54.1 95% CI= 0.2-1.2 % Change= 3.3	ES= 0.03 (T) % Likelihood= 75 Mean= 51.3 95% CI= 0.5-0.7 % Change= 0.3	ES= 0.6 (M) % Likelihood= 99.9 Mean= 55.6 95% CI= 0.8-1.7 % Change= 5.7	ES= 0.3 (S) % Likelihood= 83.1 Mean= 54.1 95% CI= 0.1-1.3 % Change= 3.3

Table 7. Evoked twitch contractile properties (kg). Lightly shaded cell indicates decreased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval.

Evoked Twitch Forces (kg)	Pre-test vs. Post-Aerobic Warm-Up Component	Pre- vs. Post-SS Intervention	Pre- vs. Post DS/DA Component	Pre- vs. 10-minute Rest Period
Control Mean pre= 13.3	ES= 0.1 (T) % Likelihood= 34.3 Mean= 13.6 95% CI=-1.3-1.9 % Change= 2.8	ES= -0.5 (M) % Likelihood= 92.5 Mean= 11.7 95% CI= -2.8-0.3 % Change= 11	ES= -0.5 (M) % Likelihood= 94.6 Mean= 11.4 95% CI=-3.4- -0.4 % Change=14.2	ES= -0.3 (S) % Likelihood= 79.3 Mean= 11.8 95% CI=-1.9-0.08 % Change=7.5
Static Stretching 30 seconds Mean pre= 14.5	ES= -0.4 (S) % Likelihood= 81.3 Mean= 12.9 95% CI= -3.7-0.4 % Change=11.5	ES= -0.5 (M) % Likelihood= 91.8 Mean= 12.4 95% CI= -4.0 - 0.2 % Change=14.5	ES= -0.3 (S) % Likelihood= 75 Mean= 13.3 95% CI= -2.9-0.3 % Change= 8.2	ES= -0.6 (M) % Likelihood= 99.4 Mean= 12 95% CI=-3.7- -1.2 % Change=17.3
Static Stretching 60 seconds Mean pre= 13.8	ES= -0.3 (S) % Likelihood= 60 Mean= 12.7 95% CI=-3.7-1.5 % Change= 8	ES= -0.6 (M) % Likelihood= 92.5 Mean= 11.4 95% CI=-4.9- -0.1 % Change18.3	ES= -0.5 (M) % Likelihood= 81.8 Mean= 12 95% CI=-4.3-0.5 % Change=13.6	ES= -0.6 (M) % Likelihood= 93.8 Mean= 11.4 95% CI=-4.7- -0.3 % Change= 18
Static Stretching 120 seconds Mean pre= 15.2	ES= -0.4 (S) % Likelihood= 85.1 Mean= 14 95% CI=-2.6-0.2 % Change= 8	ES= -1.49 (L) % Likelihood= 99.9 Mean= 11.3 95% CI=-5.4- -2.5 % Change=26.1	ES= -1.2 (L) % Likelihood= 99.7 Mean= 12 95% CI=-4.9- -1.5 % Change=22.1	ES= -1.1 (L) % Likelihood= 99.9 Mean= 12.2 95% CI=-4.0- - 1.8 % Change=19.6

Table 8. ITT% (Voluntary activation: VA) performance. Shaded cell indicates increased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval.

ITT % (VA)	Pre-test vs. Post-Aerobic Warm-Up Component	Pre- vs. Post-SS Intervention	Pre- vs. Post DS/DA Component	Pre- vs. 10-minute Rest Period
Control Mean pre= 89.1	ES= 0.2 (S) % Likelihood= 49.1 Mean= 90.6 95% CI= -5.2-2.3 % Change=13.5	ES= 0.01 (T) % Likelihood= 13.3 Mean= 89 95% CI= -2.9-3.1 % Change= 1	ES= 0.1 (T) % Likelihood= 40.5 Mean= 87.6 95% CI= -2.2-5.0 % Change= 7.8	ES= -0.008 (T) % Likelihood= 19.6 Mean= 89.8 95% CI= -3.7-3.7 % Change= 0.1
Static Stretching 30 seconds Mean pre= 89.9	ES= 0.07 (T) % Likelihood= 31.9 Mean= 90.8 95% CI=-3.3-1.6 % Change= 7.9	ES= 0.1 (T) % Likelihood= 43.1 Mean= 91.5 95% CI= -4.1-1.7 % Change=12.3	ES= 0.5(M) % Likelihood= 91.2 Mean= 87.6 95% CI= 0.4-6.6 % Change=28.1	ES= 0.5(M) % Likelihood= 91.6 Mean= 88.4 95% CI= 0.3-6.5 % Change=29.7
Static Stretching 60 seconds Mean pre= 87.9	ES= 0.1 (T) % Likelihood= 29.5 Mean= 86.8 95% CI= -1.9-4.2 % Change= 8.6	ES= 0.1 (T) % Likelihood= 41.6 Mena= 86.3 95% CI= -1.6-4.8 % Change=11.7	ES= 0.4 (S) % Likelihood= 80.8 Mean= 84.6 95% CI= -0.7-8.0 % Change= 24	ES= 0.0001 (T) % Likelihood= 16.7 Mean= 88.3 95% CI= -3.9-3.9 % Change= 0.2
Static Stretching 120 seconds Mean pre= 90.5	ES= -0.008 (T) % Likelihood= 8.3 Mean= 90.5 95% CI= -1.8-1.8 % Change=0.1	ES= 0.2 (S) % Likelihood= 53.7 Mean= 89.1 95% CI= -1.8-4.5 % Change= 2.6	ES= 0.0006 (T) % Likelihood= 12.1 Mean= 90.4 95% CI= -2.1-2.2 % Change= 0.5	ES= 0.4 (M) % Likel3hood= 94.3 Mean= 87.7 95% CI= 0.8-4.5 % Change=21.1

Table 9. Electromechanical delay (EMD) duration (s). Shaded cells indicate increased performance. Lightly shaded cells indicated decreased performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval.

EMD (s)	Pre-test vs. Post-Aerobic Warm-Up Component	Pre- vs. Post-SS Intervention	Pre- vs. Post DS/DA Component	Pre- vs. 10-minute Rest Period
Control Mean pre= 0.051	ES= -0.2 (S) % Likelihood= 62.4 Mean= 0.047 95% CI= -0.008- 0.0008 % Change= 5.3	ES= -0.15 (T) % Likelihood= 42.1 Mean= 0.049 95% CI= -0.006- 0.003 % Change= 3.3	ES= -0.05 (S) % Likelihood= 92.5 Mean= 0.045 95% CI= -0.01- 0.0006 % Change=11.1	ES= -0.1 (T) % Likelihood= 40 Mean= 0.048 95% CI= -0.007- 0.005 % Change= 2.9
Static Stretching 30 seconds Mean pre= 0.046	ES= -0 (T) % Likelihood= 44.7 Mean= 0.46 95% CI= -0.004- 0.004 % Change=0	ES= -0.04 (S) % Likelihood= 76.6 Mean= 0.050 95% CI= -0.0008- 0.006 % Change= 6	ES= 0 (T) % Likelihood= 18.7 Mean= 0.046 95% CI= -0.02- 0.02 % Change= 0	ES= 0.06 (T) % Likelihood= 25 Mean= 0.047 95% CI= -0.002- 0.003 % Change= 2.1
Static Stretching 60 seconds Mean pre= 0.047	ES= -0.1 (T) % Likelihood= 30 Mean= 0.048 95% CI= -0.003- 0.005 % Change= 2.3	ES= -0.3 (S) % Likelihood= 77.2 Mean= 0.051 95% CI= -0.007- 0.008 % Change= 7.3	ES= -0.2 (S) % Likelihood= 19.9 Mean= 0.046 95% CI= -0.004- 0.0.004 % Change= 0.7	ES= -0.2 (S) % Likelihood= 55.3 Mean= 0.049 95% CI= -0.002- 0.007 % Change= 5
Static Stretching 120 seconds Mean pre= 0.046	ES= -0.26 (S) % Likelihood= 60 Mean= 0.048 95% CI= -0.001- 0.006 % Change=5	ES= -0.58 (M) % Likelihood= 95.6 Mean= 0.05 95% CI= 0.001- 0.009 % Change=11.7	ES= -0.3 (S) % Likelihood= 77 Mean= 0.044 95% CI= -0.006- 0.002 % Change= 4.7	ES= -0.1 (T) % Likelihood= 19 Mean= 0.08 95% CI= -0.001- 0.003 % Change= 3.5

3.9 Appendices

Table 10. Hamstrings MVIC force production (Kg). Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings MVC Force (kg)	**Pre-test vs. Aerobic Warm-Up Component**	**Pre vs. Post-SS Intervention**	**Pre vs. Post DS/DA Component**	**Pre vs. 10-minute Rest Period**
Control Mean pre 36.4	ES= 0.3 (S) % Likelihood= 62.9 Mean= 34.2 95% CI=-4.7-0.2 % Change= 6.1	ES= 0.2 (T) % Likelihood= 40.2 Mean= 35.1 95% CI=-3.7-1.2 % Change= 3.5	ES= 0.2 (T) % Likelihood= 19.4 Mean= 35.6 95% CI= -2.7-0.9 % Change= 3.4	ES= 0.2 (S) % Likelihood= 58.7 Mean= 34.5 95% CI=-4.5-0.9 % Change=5.1
Static Stretching 30 seconds Pre= 36.7	ES= 0.2(S) % Likelihood= 45.9 Mean= 35 95% CI=-4.1-0.5 % Change= 4.9	ES= 0.2 (S) % Likelihood= 39.0 Mean= 34 95% CI=-3.2-0.9 % Change= 3.4	ES= 0.2 (S) % Likelihood= 33.1 Mean= 35.3 95% CI=-3.6-0.8 % Change= 3.9	ES= 0.2 (S) % Likelihood= 59.1 Mean= 33.4 95% CI=-4.2-0.8 % Change=4.9
Static Stretching 60 seconds Pre= 34.1	ES=0.08 (T) % Likelihood= 11.4 Mena= 34.9 95% CI=-2.5-3.9 % Change= 3.3	ES= 0.14 (T) % Likelihood= 34.6 Mean= 33.7 95% CI=-4.1-1.5 % Change= 3.9	ES= 0.15 (T) % Likelihood= 41.8 Mean= 33.5 95% CI=-5.5-2.6 % Change= 4.3	ES= 0.05 (T) % Likelihood= 23.4 Mean= 33.6 95% CI=-4.5-3.6 % Change=2.5
Static Stretching 120 seconds Pre= 32.1	ES= 0.1 (T) % Likelihood= 24.5 Mean= 31.4 95% CI=-2.3-1.2 % Change= 2.1	ES= 0.2 (T) % Likelihood= 43.9 Mena= 30.9 95% CI=-2.5-0.2 % Change= 3.7	ES= 0.08 (T) % Likelihood= 23.3 Mean= 31.5 95% CI=-2.5-1.4 % Change= 1.7	ES= 0.2 (T) % Likelihood= 61.9 Mean= 30.5 95% CI=-3.0-0.1 % Change=4.6

Table 11. Quadriceps F100 force production performance (Kg). Lightly shaded cell means a decrease in performance. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval.

Quadriceps F100 (kg)	**Pre-test vs. Aerobic Warm-Up Component**	**Pre vs. Post-SS Intervention**	**Pre vs. Post DS/DA Component**	**Pre vs. 10-minute Rest Period**
Control Mean pre= 19.8	ES= -0.04 (T) % Likelihood= 13.6 Mean= 19.3 95% CI= -4.3-3.3 % Change= 2.7	ES= -0.05(T) % Likelihood= 19.4 Mean= 19.1 95% CI= -5.1-3.5 % Change= 3.9	ES= -0.04 (T) % Likelihood= 11.1 Mean= 19.3 95% CI= -3.9-2.7 % Change= 3	ES= 0.02 (T) % Likelihood= 3.2 Mean= 20.1 95% CI= -2.7-3.3 % Change= 2.5
Static Stretching 30 seconds Mean pre= 17.4	ES= 0.1 (T) % Likelihood= 31.5 Mean= 19.1 95% CI= -3.8-7.1 % Change= 8.6	ES= 0.2 (S) % Likelihood= 39.3 Mean=19.7 95% CI= -2.9-7.4 % Change=11.4	ES= 0.2 (S) % Likelihood= 41.4 Mean= 19.8 95% CI= -3.1-7.8 % Change=11.8	ES= 0.1 (T) % Likelihood= 17.4 Mean= 18.2 95% CI= -4.0-5.5 % Change= 4.1
Static Stretching 60 seconds Mean pre= 22.3	ES= 0.01(T) % Likelihood= 11.2 Mean= 22.6 95% CI= -5.2-2.2 % Change= 1.4	ES= -0.2 (S) % Likelihood= 57.6 Mean= 20.3 95% CI= -8.4-2.0 % Change=13.6	ES= 0.003 (T) % Likelihood= 14.2 Mean= 23.5 95% CI= -5.2-5.3 % Change= 0.2	ES= -0.2 (S) % Likelihood= 49.7 Mean= 19.7 95% CI=-7.4-2.1 % Change=11.8
Static Stretching 120 seconds Mean pre= 21	ES= -0.04 (T) % Likelihood= 11.8 Mean= 20.3 95% CI= -4.2-3.0 % Change=3	ES= -0.4 (S) % Likelihood= 89.1 Mean= 14.9 95% CI= -11.3- -0.7 % Change=29.6	ES= -0.2 (S) % Likelihood= 42.9 17.2 95% CI= -7.1-3.0 % Change=10.8	ES= -0.1 (S) % Likelihood= 39.7 17.8 95% CI=-7.9-4.2 % Change=9.1

Table 12. Hamstrings F100 force production (Kg). Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings F100 (kg)	Pre-test vs. Aerobic Warm-Up Component	Pre vs. Post-SS Intervention	Pre vs. Post DS/DA Component	Pre vs. 10-minute Rest Period
Control Mean= 6.2	ES= 0.4(S) % Likelihood= 74 Mean= 7.6 95% CI= -1.9-3.9 % Change=18.1	ES= -0.08 (T) % Likelihood= 33.5 Mean= 5.9 95% CI= -2.2-1.6 % Change= 4.9	ES= -0.2 (S) % Likelihood= 52.7 Mean= 5.4 95% CI= -2.6-1.2 % Change=11.8	ES= -0.3 (S) % Likelihood= 65.3 Mean= 4.5 95% CI=-3- 1.3 % Change=16.9
Static Stretching 30 seconds Mean pre= 5.5	ES= -0.07 (T) % Likelihood= 31.4 Mean= 5.5 95% CI= -3.1-2.4 % Change= 6	ES= 0.008 (T) % Likelihood= 12.9 Mean= 5.5 95% CI= -1.8-1.8 % Change= 0.8	ES= -0.008 (T) % Likelihood= 24.2 Mean= 5.5 95% CI= -2.8-2.8 % Change= 0.3	ES= 0.1 (T) % Likelihood= 36.6 Mean= 4.9 95% CI=-2.7-1.5 % Change=11.4
Static Stretching 60 seconds Mean pre= 6.1	ES= -0.1 (T) % Likelihood= 42.1 Mean= 5.7 95% CI= -2.8-2.1 % Change= 6.1	ES= 0.2 (S) % Likelihood= 15.9 Mean= 6.7 95% CI= -1.8-3.0 % Change= 8.9	ES= -0.5 (M) % Likelihood= 70.3 Mean= 4.5 95% CI=-4.1-1.5 % Change=12.4	ES= 0.2 (S) % Likelihood= 47.9 Mean= 5.6 95% CI= -3.2-2.2 % Change= 8.6
Static Stretching 120 seconds Mean pre= 5.1	ES= 0.3 (S) % Likelihood= 65.2 Mean= 6.2 95% CI= -0.6-2.9 % Change= 18.8	ES= -0.1 (T) % Likelihood= 37.4 Mean= 4.5 95% CI= -2.1-0.9 % Change= 12.3	ES= -0.3 (S) % Likelihood= 59.4 Mean= 4 95% CI= -2.9-0.8 % Change=20.7	ES= -0.3 (S) % Likelihood= 69.5 Mean= 3.7 95% CI= -3.7-1.0 % Change= 26.3

Table 13. Quadriceps EMG (mV). Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps EMG	**Pre-test vs. Aerobic Warm-Up Component**	**Pre vs. Post-SS Intervention**	**Pre vs. Post DS/DA Component**	**Pre vs. 10-minute Rest Period**
Control Mean pre= 0.041	ES= -0.07 (T) % Likelihood= 1.87 Mean= 0.039 95% CI= -0.005- 0.002 % Change= 4.3	ES= -0.05 (T) % Likelihood= 2.36 Mean= 0.039 95% CI= -0.006- 0.004 % Change= 3.2	ES= -0.1 (T) % Likelihood= 15.1 Mean= 0.038 95% CI=-0.008- 0.002 % Change= 3.8	ES= 0.05 (T) % Likelihood= 6.02 Mean= 0.042 95% CI=-0.003- 0.006 % Change= 4.3
Static Stretching 30 seconds Mean pre= 0.053	ES= -0.1 (T) % Likelihood= 0.6 Mean= 0.05 95% CI= -0.009- 0.002 % Change= 6	ES= -0.06 (S) % Likelihood= 1.17 Mean= 0.051 95% CI= -0.01- 0.004 % Change= 5.2	ES= -0.1 (T) % Likelihood= 9.2 Mean= 0.049 95% CI=-0.01- 0.002 % Change= 9.3	ES= -0.15 (T) % Likelihood= 27.7 Mean= 0.047 95% CI= -0.01- 0.002 % Change=11.8
Static Stretching 60 seconds Mean pre= 0.044	ES= -0.1 (T) % Likelihood= 31.7 Mean= 0.04 95% CI=-0.9- 0.9 % Change= 8.5	ES= 0.02 (T) % Likelihood= 0.02 Mean= 0.039 95% CI=-2.4- 2.4 % Change= 2.2	ES= -0.1 (T) % Likelihood= 37.9 Mean= 0.6 95% CI=-2.6- 2.6 % Change= 6.3	ES= 0.01 (T) % Likelihood= 4.5 Mean= 0.039 95% CI= -3.4- 3.5 % Change= 0.9
Static Stretching 120 seconds Mean pre= 0.065	ES= -0.3 (S) % Likelihood= 62.9 Mean= 0.052 95% CI=-0.9- 0.9 % Change=19.3	ES= -0.3 (S) % Likelihood= 61.2 Mean= 0.053 95% CI=-2.3- 2.3 % Change=19.2	ES= -0.2 (T) % Likelihood= 52.4 Mean= 0.056 95% CI=-2.4- 2.3 % Change=13.8	ES= -0.2 (T) % Likelihood= 56.9 Mean= 0.054 95% CI=-3.2- 3.1 % Change13.8

Table 14. Hamstrings EMG (mV). Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings EMG	Pre-test vs. Aerobic Warm-Up Component	Pre vs. Post-SS Intervention	Pre vs. Post DS/DA Component	Pre vs. 10-minute Rest Period
Control Mean pre= 0.04	ES= -0.09 (T) % Likelihood= 49.8 Mean= 0.038 95% CI=-0.02- 0.009 % Change= 5.3	ES= 0.2 (S) % Likelihood= 44.1 Mean= 0.044 95% CI= -1.1- 1.1 % Change= 8.2	ES= 0.3 (S) % Likelihood= 58.3 Mean= 0.047 95% CI= -0.01- 0.03 % Change=14.5	ES= 0.31 (S) % Likelihood= 58.6 Mean= 0.047 95% CI=-0.02- 0.03 % Change=14.9
Static Stretching 30 seconds Mean pre= 0.053	ES= 0.05 (T) % Likelihood= 3.7 Mean= 0.054 95% CI=- 0.003- 0.007 % Change= 4.1	ES= -0.02 (T) % Likelihood= 13.6 Mean= 0.052 95% CI=- 0.008- 0.006 % Change= 1.7	ES= 0.08 (T) % Likelihood= 8.6 Mean= 0.056 95% CI= -0.03- 0.009 % Change= 5.5	ES= 0.1 (T) % Likelihood= 26.3 Mean= 0.057 95% CI=- 0.002- 0.01 % Change= 9.1
Static Stretching 60 seconds Mean pre= 0.046	ES= 0.3 (S) % Likelihood= 6.0 Mean= 0.052 95% CI=-2.6- 2.3 % Change=12.9	ES= -0.1 (T) % Likelihood= 25.7 Mean= 0.049 95% CI= -2.5- 2.5 % Change= 6	ES= -0.1 (T) % Likelihood= 19.7 Mean= 0.043 95% CI=-2.5- 2.5 % Change= 5.3	ES= 0.1 (T) % Likelihood= 32.4 0.048 95% CI= -2.5- 2.5 % Change= 6.5
Static Stretching 120 seconds Mean pre= 0.076	ES= -0.2 (S) % Likelihood= 47 Mean= 0.068 95% CI=-0.03- 0.01 % Change= 9.3	ES= 0.02(T) % Likelihood= 0.4 Mean= 0.076 95% CI=-0.02- 0.03 % Change= 1	ES= -0.3 (S) % Likelihood= 61.1 Mean= 0.066 95% CI=-2.4- 2.4 % Change=14.2	ES= -0.1 (T) % Likelihood= 36.8 Mean= 0.07 95% CI= -3.1- 3.1 % Change= 7.5

Table 15. Quadriceps m-wave force (Kg). Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

M-Wave	Pre-test vs. Aerobic Warm-Up Component	Pre vs. Post-SS Intervention	Pre vs. Post DS/DA Component	Pre vs. 10-minute Rest Period
Control Mean pre= 6.8	ES= -0.02 (T) % Likelihood= 8.1 Mean= 6.7 95% CI= -1.0-0.8 % Change= 2.5	ES= -0.03 (T) % Likelihood= 12.7 Mean= 6.7 95% CI= -1.2-0.9 % Change= 1.7	ES= -0.02(T) % Likelihood= 11.1 Mean= 6.7 95% CI= -1.2-0.9 % Change= 1.4	ES= 0.2 (T) % Likelihood= 38.5 Mean= 7.5 95% CI= -0.5-1.7 % Change= 8
Static Stretching 30 seconds Mean pre= 7.5	ES= -0.1(T) % Likelihood= 22.2 Mean= 6.9 95% CI= -1.5-0.24 % Change= 8.3	ES= 0.4 (S) % Likelihood= 72 Mean= 9.1 95% CI= -0.9-4.1 % Change=17.9	ES= 0.09 (T) % Likelihood= 19.9 Mean= 7.9 95% CI= -0.8-1.6 % Change= 5.5	ES= 0.07 (T) % Likelihood= 20.9 Mean= 7.9 95% CI= -1.1-1.8 % Change= 4.8
Static Stretching 60 seconds Mean pre= 6.6	ES= 0.1 (T) % Likelihood= 4.8 Mean= 6.9 95% CI= -0.1-0.8 % Change= 5	ES= -0.3 (S) % Likelihood= 62.5 Mean= 5.5 95% CI= -3.3-1.1 % Change=16.3	ES= -0.3(S) % Likelihood= 59.9 Mean= 5.6 95% CI= -3.3-1.3 % Change=15.4	ES= 0.3 (S) % Likelihood= 69 Mean= 5.3 95% CI= -3.5-1.0 % Change=19.5
Static Stretching 120 seconds Mean pre=8.4	ES= -0.006 (T) % Likelihood= 2.7 Mean= 8.4 95% CI= -1.1-1.1 % Change= 0.5	ES= -0.05 (T) % Likelihood= 3.2 Mean= 8.7 95% CI= -1.1-0.5 % Change= 3.5	ES= 0.01 (T) % Likelihood= 3.7 Mean= 8.5 95% CI= -1.3-1.4 % Change= 1	ES= -0.2(T) % Likelihood= 41 Mean= 7.5 95% CI= -2.9-1.1 % Change=10.7

Table 16. Quadriceps m-wave duration (ms). Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

M-Wave Duration	Pre-test vs. Aerobic Warm-Up Component	Pre vs. Post-SS Intervention	Pre vs. Post DS/DA Component	Pre vs. 10-minute Rest Period
Control Mean pre= 0.1	ES= -0.3 (S) % Likelihood= 58.4 Mean= 0.06 95% CI= -0.2-0.06 % Change= 6	ES= -0.3 (S) % Likelihood= 58.1 Mean= 0.06 95% CI= -0.2-0.06 % Change= 6	ES= -0.2 (S) % Likelihood= 55.1 Mean= 0.07 95% CI= -0.2-0.06 % Change= 4	ES= -0.2 (S) % Likelihood= 58 Mean= 0.06 95% CI= -0.2-0.06 % Change=6
Static Stretching 30 seconds Mean pre= 0.08	ES= -0.18 (T) % Likelihood= 44.7 Mean= 0.07 95% CI= -0.02-0.01 % Change= 7.9	ES= -0.05 (T) % Likelihood= 21.7 Mean= 0.08 95% CI= -0.02-0.01 % Change= 2.4	ES= 0.0008 (T) % Likelihood= 18.7 Mean= 0.08 95% CI= -0.02-0.02 % Change= 0.4	ES= 0.08 (T) % Likelihood= 30 Mean= 0.08 95% CI= -0.01-0.02 % Change= 3.7
Static Stretching 60 seconds Mean pre= 0.06	ES= -0.3 (S) % Likelihood= 58.8 Mean= 0.07 95% CI= -1.7-0.6 % Change=24.7	ES= -0.3 (S) % Likelihood= 59 Mean= 0.09 95% CI= -1.8-0.7 % Change=14.1	ES= -0.3 (S) % Likelihood= 59.8 Mean= 0.07 95% CI= -1.9-0.7 % Change= 4.5	ES= -0.3 (S) % Likelihood= 60 Mean= 0.06 95% CI= -1.9-0.7 % Change=12.7
Static Stretching 120 seconds Mean pre= 0.08	ES= -0.01 (T) % Likelihood= 3.6 Mean= 0.07 95% CI= -1.3-1.3 % Change= 0.4	ES= -0.005 (T) % Likelihood= 23.9 Mean= 0.07 95% CI= -0.01-0.008 % Change= 1.5	ES= 0.003 (T) % Likelihood= 25.7 Mean= 0.08 95% CI= -0.01-0.01 % Change= 0.1	ES= 0.2 (T) % Likelihood= 45.8 Mean= 0.08 95% CI= -0.009- 0.001 % Change= 4.8

Table 17. Hip flexion (hamstrings) range of motion (ROM) performance (degrees) control vs. SS 30s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
Control vs. SS 30s	ES= -0.1 (T) % Likelihood= 13.9 95% CI= -4.2-3.9	ES= 0.3 (S) % Likelihood= 66.5 95% CI= -1.6-8.5	ES= 0.1 (T) % Likelihood= 30.1 95% CI= -3.6-6.5

Table 18. Hip flexion (hamstrings) range of motion (ROM) performance (degrees) control vs. SS 60s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
Control vs. SS 60s	ES= 0.07 (T) % Likelihood= 26.5 95% CI= -4.-5.6	ES= 0.02 (T) % Likelihood= 14.2 95% CI= -3.7-4.3	ES= -0.02 (T) % Likelihood= 13.1 95% CI= -4.6-3.9

Table 19. Hip flexion (hamstrings) range of motion (ROM) performance (degrees) SS 30s vs. SS 60s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
SS 30s vs. SS 60s	ES= 0.06 (T) % Likelihood= 19.5 95% CI= -2.9-4.0	ES= -0.3 (S) % Likelihood= 65.9 95% CI= -7.2-1.3	ES= -0.2 (S) % Likelihood= 46.4 95% CI= -6.2-2.2

Table 20. Hip flexion (hamstrings) range of motion (ROM) performance (degrees) SS 30s vs. SS 120s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
SS 30s vs. SS 120s	ES= 0.15 (T) % Likelihood= 29.3 95% CI= -2.4-6.0	ES= -0.3 (S) % Likelihood= 46.3 95% CI= -5.2-2.5	ES= 0.1 (T) % Likelihood= 43.5 95% CI= -7.9-10.9

Table 21. Hip flexion (hamstrings) range of motion (ROM) performance (degrees) SS 60s vs. SS 120s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Hamstrings ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
SS 60s vs. SS 120s	ES= 0.2 (S) % Likelihood= 49.9 95% CI= -1.5-7.1	ES= -0.2 (S) % Likelihood= 60.2 95% CI= -1.3-7.8	ES= -0.3 (T) % Likelihood= 61.6 95% CI= -5.1-12.1

Table 22. Hip Extension (Quadriceps) ROM performance (degrees) Control vs. SS 60s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
Control vs. SS 60s	ES= 0.2 (S) % Likelihood= 54.9 95% CI= -6.2-1.5	ES= 0.3 (S) % Likelihood= 71 95% CI= -7.7-0.6	ES= 0.05 (T) % Likelihood= 30.1 95% CI= -4.5-3.3

Table 23. Hip Extension (Quadriceps) ROM performance (degrees). SS 30s vs. SS 60s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
SS 30s vs. SS 60s	ES= 0.02 (T) % Likelihood= 14.6 95% CI= -1.1-8.0	ES= 0.01 (T) % Likelihood= 1.9 95% CI= -4.1-3.8	ES= -0.1 (T) % Likelihood= 33.9 95% CI= -2.7-5.7

Table 24. Hip Extension (Quadriceps) ROM performance (degrees) SS 30s vs. SS 120s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
SS 30s vs. SS 120s	ES= 0.2 (S) % Likelihood= 46.9 95% CI= -6.5-2.3	ES= 0.2 (S) % Likelihood= 49.6 95% CI= -6.0-1.9	ES= 0.03 (T) % Likelihood= 0.5 95% CI= -3.9-3.1

Table 25. Hip Extension (Quadriceps) ROM performance (degrees) SS 60s vs. SS 120s condition. Acronyms: T: trivial, S: small, M: moderate, L: large, CI: confidence interval

Quadriceps ROM	SS vs. SS	DS/DA vs. DS/DA	10-minute vs. 10-minute
Control vs. SS 120s	ES= 0.2 (S) % Likelihood= 47 95% CI= -4.0-0.02	ES= 0.2 (S) % Likelihood= 48.9 95% CI= -4.3-0.4	ES= 0.1 (T) % Likelihood= 44.5 95% CI= -5.3-1.6