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The Effects of Static Stretching Versus Dynamic Stretching on Lower Extremity Joint Range of Motion, Static Balance, and Dynamic Balance

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THE EFFECTS OF STATIC STRETCHING VERSUS DYNAMIC STRETCHING ON LOWER EXTREMITY JOINT RANGE OF MOTION, STATIC BALANCE, AND DYNAMIC BALANCE

by

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ABSTRACT

THE EFFECTS OF STATIC STRETCHING VERSUS DYNAMIC STRETCHING ON LOWER EXTREMITY JOINT RANGE OF MOTION, STATIC BALANCE, AND DYNAMIC BALANCE

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The purpose of this study was to examine the effects of static stretching (SS) versus dynamic stretching (SS) on lower extremity joint range of motion (ROM), static balance, and dynamic balance. Fifteen active subjects with tight hamstring and calf muscles participated. Hip flexion and knee extension ROM angle was measured using a fluid inclinometer. A closed-chain method of measuring ankle dorsiflexion ROM was used. Static balance was assessed in single-leg stance on a force plate using the time-to-boundary (TTB) measurement. The Star Excursion Balance Test (SEBT) was used to assess dynamic balance in three directions. These measurements were assessed before and after each of three interventions: DS, SS or warm-up alone (CN). The dependent variables included ROM measures (hip flexion, knee extension, and ankle dorsiflexion), SEBT measures (anterior (ANT), posterior-medial (PM), posterior-lateral (PL)), and TTB mean in anterior-posterior (AP) and medial-lateral (ML). Repeated measures ANOVA were used to analyze the data.

There was a significant main effect ($p < 0.05$) for time. Repeated measures ANOVA showed that knee extension ROM, hip flexion ROM, ankle dorsiflexion

ROM**,** the SEBT (ANT, PM, PL) significantly ($P<0.05$) increased regardless of what intervention (SS, DS, CN) was performed. There were no significant differences ($p>0.05$) for the TTB (ML, AP) and there were also no significant interaction ($p>0.05$) between interventions (SS, DS, CN) and time.

The less stiff muscles and more slack connective tissue around the joints following stretching might attribute to the increased joint ROM. The enhanced ability to maintain dynamic balance after an increased flexibility might be due to a desensitized stretch reflex. A less responsive stretch reflex could suppress the postural deviations, enhance the proprioceptive input, and thus make it easier to establish equilibrium. Another contributor might be elevated muscle and body temperature, which enhance nerve conduction velocity. The sensory systems might play a dominant role in regulating the static postural control. Additional research is needed to more clearly understand the relationship between altered ROM, balance and stretching.

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CHAPTER 1: INTRODUCTION

Background

One of the most common things that individuals are instructed to do prior to exercise is “warm-up”. A regular warm-up usually consists of three components: aerobic exercise, stretching, and a rehearsal of the movements that will be used in the subsequent training exercise or sports competition. Stretching is often utilized for a wide variety of populations to be an essential part of a warm-up, which includes ballistic stretching, proprioceptive neuromuscular facilitation (PNF) stretching, static stretching (SS), and dynamic stretching (DS) (Ranna & Koslow, 1984; Sady, Wortman, & Blanke, 1982). The benefits of stretching include, but are not limited to improve joint range of motion (ROM), enhance muscular performance, and reduced risk of injury (Pasanen, Parkkari, Pasanen, & Kannus, 2009; Shellock & Prentice, 1985; G. J. Wilson, Murphy, & Pryor, 1994; Witvrouw, Mahieu, Danneels, & McNair, 2004; W. B. Young & Behm, 2002). However, there was recently doubt over the effectiveness of SS, as studies have demonstrated that SS decreased an individual’s performance in force, strength, and power (A. Nelson & Kokkonen, 2001; Power, Behm, Cahill, Carroll, & Young, 2004). It is therefore increasingly suggested that individuals should turn to DS warm-up to more closely mimic movements in the subsequent training exercises or sports competition, and DS has been shown to improve muscular performance (Fletcher, 2010; Little & Williams, 2006; McMillian, Moore, Hatler, & Taylor, 2006). Since balance is important for a wide range of populations that include recreationally active individuals, elite athletes, and elderly to not only produce optimal performance but also to prevent fall or injury, it is critical to understand how physical intervention affects it. One are that has not been thoroughly investigated is the effects of stretching on balance. Postural stability, or balance, relies heavily on the contribution of information from proprioceptive receptors located within the muscle and connective tissue. Because stretching changes the length of the muscles and tendons, it is possible that either DS or SS may have an influence on proprioception, and therefore balance.

Ballistic stretching (BS) is a kind of passive stretch that forces the limb into a quick and jerking motion, which suddenly produces a bounce beyond a leg or arm's normal ROM. Thus, it is recommended that individuals should not perform BS unless they are high-level athletes or being supervised, otherwise it may cause serious injury (Sady et al., 1982).

Proprioceptive neuromuscular facilitation (PNF) stretching, defined as a combination of passive stretch and isometric contractions of the target muscle, is often utilized to increase the joint ROM, muscular strengthen, and neuromuscular control in a clinical and rehabilitation environment (Marek et al., 2005). However, PNF stretching has been proven to decrease vertical jump performance and leg extension power in recreationally active individuals (Bradley, Olsen, & Portas, 2007; Marek et al., 2005). Therefore, it is suggested that PNF stretching should not be performed immediately prior to an explosive movement during physical activity.

Static stretching (SS) is described as gradually lengthening a muscle to an elongated position as tolerated to a point of discomfort, and holding position for a particular length of time. SS has often been widely uzilized to be a component of a warm up in the training exercise or sports competition (De Vries, 1962). Traditionally, SS has been shown to increase the joint ROM, inprove performance, and prevent injury (Bandy, Irion, & Briggler, 1997; Smith, 1994; W. B. Young & Behm, 2002) . Increased ROM was one of the greastest benefits derived from SS. This was primarily due to changes in the length and stiffness of musculotendinous unit (MTU), with greater ROM generated by a less stiff MTU (G. Wilson, Wood, & Elliott, 1992). However, there was recently doubt over the effectiveness of SS. Studies have demonstrated that SS decreased an individual's performance in force, strength, and power. These performances included maximal voluntary contraction (MVC) isometric force, one repetition maximum lifts, vertical jump, sprint, running, and agility effects (Behm, Bambury, Cahill, & Power, 2004; A. Nelson & Kokkonen, 2001; Power et al., 2004). Additionally, several studies have concluded that SS had no effect or increased the risk of injury (Chaouachi et al., 2008; Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; McHugh & Cosgrave, 2009; McNeal & Sands, 2003). Therefore, the use of SS remains controversial.

It is increasingly suggested that individuals should turn to dynamic stretching (DS) designed warm-up due to the close mimic movements in the subsequent training exercise or sports competition, rather than SS (McMillian et al., 2006; Yamaguchi & Ishii, 2005). Dynamic stretching is defined as a controlled movement through the joint active range of motion while moving but not exceeding individual's extensibility limits (Fletcher & Jones, 2004). Some studies have demonstrated that DS exhibited similar increases in ROM as SS, while other authors suggested that SS created greater effects on ROM than DS (Bandy, Irion, & Briggler, 1998; Beedle & Mann, 2007; Herman & Smith, 2008). Thus, there is no consensus on the effects of DS or SS on ROM. Additionally, improved muscular performance following DS were seen in the areas of shuttle run time, medicine ball throw distance, jump and sprint performance, and leg extension power (Fletcher, 2010; Fletcher & Anness, 2007; Little & Williams, 2006; McMillian et al., 2006; Thompsen, Kackley, Palumbo, & Faigenbaum, 2007; Yamaguchi & Ishii, 2005; Yamaguchi, Ishii, Yamanaka, & Yasuda, 2007). Several possible mechanisms by which DS improved muscular performance could be elevated muscle and body temperature (Fletcher & Jones, 2004), post-activation potentiation (PAP) in the stretched muscle (Torres et al., 2008), and stimulation of the nervous system (Yamaguchi & Ishii, 2005). However, these mechanisms have not been fully explored and the reason behind why DS helps performance is as yet unknown. Since coaches, athletic trainers, and fitness professinals are increasingly aware of the advantage of DS in improving muscular performance, the use of DS rather than SS for the warm-up is increasingly more common. However, we do not yet know the effects that DS has on balance.

In biomechanics, balance is defined as the ability to maintain the individual's center of gravity within their base of support with minimal postural sway (Shumway-Cook, Anson, & Haller, 1988). Balance can be separated into static balance and dynamic balance.

Static balance is defined as individual maintaining a stable base of support while minimizing segment and body movement (Bressel, Yonker, Kras, & Heath, 2007). Instruments, such as the Balance Error Scoring System or Berg Balance Scale, have been widely used to measure static balance (P. Gribble, Hertel, & Denegar, 2007), however they are somewhat subjective. Time-to-boundary (TTB) provides an objective novel postural control approach to assess static balance. A lower TTB outcome indicates greater postural instability since the center of pressure (CoP) is closer in time to reaching the boundary of the base of support (van Emmerik & van Wegen, 2002). TTB measures can assess CoP excursions in relation to the boundaries of the base of stability that is not addressed by traditional postural control measures and has been proven to be more sensitive at detecting improvements in static postural control compared with traditional CoP-based measures (Hertel & Olmsted-Kramer, 2007; Mckeon et al., 2008). However, stability in static balance might not translate necessarily to postural control during dynamic movements due to the task and environmental demands of a dynamic movement being very different from standing quietly.

Dynamic balance is defined as an individual performing a purposeful movement around a base of support without compromising the base of support. Dynamic balance measurements, such as Star Excursion Balance test or wobble board, have been demonstrated to be more closely to mimic demands of physical activity than static balance assessments (P. A. Gribble, Hertel, & Plisky, 2012). The Star Excursion Balance Test (SEBT) is a cost-effective, easy-to-use clinical technique to measure dynamic balance in the rehabilitation, injury evaluation and prediction, and research applications (Hertel, Miller, & Denegar, 2000; Kinzey & Armstrong, 1998; Plisky, Rauh, Kaminski, & Underwood, 2006). The SEBT requires individual's postural control, strength, range of motion, coordination and proprioceptive abilities. The farther distance the touching leg reaches, the better dynamic balance it displays (Hertel et al., 2000). Hertel et al (2006) simplified the SEBT that using three reach directions (anterior, posteromedial, and posterolateral) from the center of the grid to identify individuals with chronic ankle instability (CAI) (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). To make valid comparisons of SEBT, reaching distances need to be normalized to individual's limb length (P. A. Gribble & Hertel, 2003). In addition, several other anthropometric and physiologic factors, such as range of motion, fatigue, or interventions, have also contributed to SEBT performance. Given that the interference between dorsiflexion in the ankle, knee flexion, and hip flexion with the SEBT (P. A. Gribble, Hertel, Denegar, & Buckley, 2004; P. A. Gribble et al., 2012; M.C. Hoch, Staton, & McKeon, 2011), it is reasonable to assume that alteration in ROM following stretching could affect the performance of the SEBT, and therefore dynamic balance.

Postural stability, or balance, relies heavily on the contribution of information from proprioceptive receptors located within the muscle and connective tissue. Proprioception includes input from sensory neurons in the inner ear and in the stretch receptors in the muscles and the joint ligaments, is an important contributor to control postural stability (Di Giulio, Maganaris, Baltzopoulos, & Loram, 2009). It is possible that a small change in the activity of a proprioceptor could lead to a greater change in balance (Diener, Dichgans, Guschlbauer, & Mau, 1984).Proprioceptors affect postural stability through the relationship between sensitivity and muscle stiffness, or the stretch-reflex response (L. M. Nashner, 1981). Stiffer muscles produce a greater reflex response (Sinkjaer, Toft, Andreassen, & Hornemann, 1988) which leads to a more rapid response to slight perturbations of muscle length. A faster response to perturbation would result in better balance (Petit, Filippi, Emonet-Denand, Hunt, & Laporte, 1990). Since stretching has the ability to change the muscle stiffness, muscle length, and increase joint ROM, it is reasonable to postulate that stretching could affect proprioception and therefore balance (Behm et al., 2004; Chong & Do, 2002; McHugh & Cosgrave, 2009).

There was little research focusing on the relationship between balance and stretching. Several studies support that SS enhanced or had no adverse effect on dynamic balance (P.B. Costa, B.S. Graves, M. Whitehurst, & P.L. Jacobs, 2009; Handrakis et al., 2010; Lewis, Brismée, James, Sizer, & Sawyer, 2009; A. G. Nelson, Kokkonen, Arnall, & Li, 2011). Costa et al (2009) evaluated the effects of different durations of SS on dynamic balance. The results of this study indicated that SS of 45 s did not adversely affect dynamic balance while SS with 15 s may improve dynamic balance (P.B. Costa et al., 2009). While Handrakis et al (2010) found that ten minutes of acute SS enhanced dynamic balance in active middle-aged adults (Handrakis et al., 2010). Furthermore, Nelson et al (2011) investigated the acute effect of SS on postural stability in non-balance trained individuals compared with experienced balance trainers. They found that SS improved balance for non-balance trained individuals, but not for those with greater balance experience (A. G. Nelson et al., 2011). On the other hand, studies indicated that SS resulted in adverse effects on static balance (Behm et al., 2004). Behm et al (2004) evaluated the effect of acute lower limb SS on static balance, force, proprioception, reaction time and movement time. It found that there was a significant ($P < 0.009$) decrease in balance scores in the SS condition (decreasing for 9.2%) compared with the control condition (increasing for 17.3%) (Behm et al., 2004). This was consistent with Nagano et al (2006)'s finding, which suggested that SS of the calf muscles increased postural sway, and thus adversely affected static balance (Nagano, Yoshioka, Hay, Himeno, & Fukashiro, 2006). Since many training exercise or sports competition requires both types of balance, static and dynamic, it would be therefore advantageous to incorporate static and dynamic balance task together when investigating the effect of SS on balance performance in an integrated research environment.

As discussed above, the benefits of DS on muscular performance have been distinctly proven and there is a tendency to utilize DS to be a component of a warm-up rather than SS. However, it is still unclear the effects of DS on static or dynamic balance, since no research has been conducted in this area. This study will add preliminary research to reveal the effects of DS on static balance or dynamic balance.

Purpose

The purpose of this study was to examine the effects of static stretching versus dynamic stretching on lower extremity joint ROM, static balance, and dynamic balance.

Specific Aims

1. To compare the effects of SS and DS on joint ROM of hip flexion, knee extension, and dorsiflexion, it was hypothesized that: 1) the SS intervention would have an increase in joint ROM of the hip, knee, and ankle, 2) the DS intervention would have an increase in joint ROM of the hip, knee, and ankle, but less than the SS group, 3) there would be no change in the joint ROM of the control intervention.
2. To compare the effects of SS and DS on static balance (TTB), it was hypothesized that: 1) the SS intervention would have a decrease in performance of static balance, 2) the DS intervention would have increased performance of static balance, 3) there would be no change static balance of the control intervention.
3. To compare the effects of SS and DS dynamic balance (SEBT), it was hypothesized that: 1) the SS intervention would have decreased dynamic balance, 2) the DS intervention would have increased dynamic balance, 3) there would be no change in the dynamic balance of the control intervention.

Delimitations

The results of this study were applied to those who are recreationally active individuals with or without hamstring or calf muscle tightness, both for men and women ages from 18-45. It was not applied to children, adults older than 45 and anyone who is not recreationally active. The results of this study only applied to static and dynamic balance, and have limited application to other athletic activities that require additional skills.

This study only examined balance performance and ROM parameters (TTB variables, SEBT scores, dorsiflexion, knee extension, and hip flexion ROM). No conclusion was made with respect to neural activation levels, such as changes in musculotendinous unit (MTU) stiffness and proprioceptive sense since they were not being examined.

Assumptions

Some assumptions were made in this study. The first assumption was that participants honestly completed the questionnaire and accurately reported their current activity level and injury/surgery history. The second assumption was that participants continued their recreationally active exercise or sports with no change of the regular physical activity's level, but refrained from it 24 hours prior to testing sessions. The third assumption was that there was no or little learning effect across the study. The learning effect was controlled by the questionnaire, orientation and data analysis that calculates different valuables between pre and post balance tests. The participants completed all trials with maximal effort was the final assumption.

Limitations

The only limitation of this study was learning effect. Although it was controlled by the questionnaire, orientation and data analysis that calculates different valuables between pre and post balance tests to a large extent, it is impossible to completely eliminate it.

Significance

The significance of this study was that it will add the body knowledge that will allow coaches, athletic trainers, and fitness professionals to make evidence based decisions on how to prepare the individuals with hamstring and calf muscle tightness for utilizing a proper stretching technique during warm-up session. Additionally, it will also provide basic scientific evidence on informing future research that focus on lower extremity functional balance rehabilitation with specific stretching technique.

CHAPTER 2: LITERATURE REVIEW

Introduction

A regular warm-up usually consists of three components. The first component is aerobic exercise, which raises core body and muscle temperature (Bishop, 2003a). Bishop (2003b) suggests that an aerobic warm-up at 40-60% VO_2 max for 5-10 minutes followed by 5 minutes of recovery is optimal to stimulate short-term physical function and enhance athletic performance (Bishop, 2003b). The second component is stretching that has been widely proven to enhance neuromuscular performance, including stimulates core body and muscle temperature, increases the joint range of motion (ROM), enhances muscle strength, and promotes balance and coordination (Pasanen et al., 2009; Shellock & Prentice, 1985; Witvrouw et al., 2004; W. B. Young & Behm, 2002). The third component is a rehearsal of the movements that will be used in the subsequent training exercise or sports competition (W. B. Young & Behm, 2002). The integrated warm-up components are adopted extensively for a wide of population, not only for recreationally active individuals, but also for elite athletes.

Various types of stretching technique have been developed to be applied not only in the training exercise or sports competition, but also in clinical and rehabilitation environment. These stretching techniques include ballistic stretching (BS), proprioceptive neuromuscular facilitation (PNF) stretching, static stretching (SS), and dynamic stretching (DS). Recently, there was doubt over the effectiveness of SS due to its adverse effect on performance (Chaouachi et al., 2008; Faigenbaum et al., 2005; McNeal & Sands, 2003). In addition, it is increasingly suggested that individual should turn to DS as a component of an effective warm-up due to its distinct benefits on muscular performance (McMillian et al., 2006; Yamaguchi & Ishii, 2005).

Impaired balance is a factor to provide negatively effects on athletic performance (Irrgang, Whitney, & Cox, 1994). In addition, a balance deficit is attributed to increase the risk of a fall and injury (McGuine, Greene, Best, & Leverson, 2000; Trojian & McKeag, 2006; Tropp, Ekstrand, & Gillquist, 1984). Since balance plays such an important role in the lifespan, it is critical to understand how physical interventions affect it. Proprioception was considered as one of the mechanisms to control balance and is sensitive to muscle tension and length that could be changed by stretching (Behm et al., 2004; Chong & Do, 2002; McHugh & Cosgrave, 2009). Therefore, it is reasonable to suppose that stretching could have an influence on balance.

There was little research focusing on the relationship between balance and stretching. Several studies support that SS enhanced or had no adverse effects on dynamic balance (P.B. Costa et al., 2009; Handrakis et al., 2010; Lewis et al., 2009; A. G. Nelson et al., 2011). However, Behm et al (2004) indicated that SS resulted in adverse effects on static balance (Behm et al., 2004). Since these studies separated static balance and dynamic balance task, and many training exercise or sports competition requires both types of balance, it would be advantageous to incorporate static and dynamic balance task together in an integrated research. Furthermore, it is still unclear the effects of DS on static or dynamic balance, since no research has been conducted in this area.

Therefore, the purpose of this literature review is to discuss the effects of various types of stretching techniques, static and dynamic balance, and the relationship between stretching and static or dynamic balance.

Stretching Techniques

Various types of stretching techniques have been developed in the training, sports competition, clinic, and rehabilitation settings in order to gain an increase in range of motion (ROM), an improvement in muscular performance, and reduce the risk of injury. These stretches include ballistic stretching (BS), proprioceptive neuromuscular facilitation (PNF) stretching, static stretching (SS), and dynamic stretching (DS) (Ranna & Koslow, 1984; Sady et al., 1982).

Ballistic Stretching

Ballistic stretching is a kind of stretch that forces the limb into a quick and jerking motion, which suddenly produces a bounce beyond a leg or arm’s normal ROM. Thus, it is recommended that individuals should not perform BS unless they are high-level athletes or supervised by a personal trainer, otherwise it may cause serious injury (Bradley et al., 2007; Sady et al., 1982). In addition, it has been demonstrated that BS resulted a decrease in the jump performance and maximal strength (Bradley et al., 2007; A. Nelson & Kokkonen, 2001). Bradley et al (2007) found that there was a decrease in the vertical jump performance (2.7%, $p > 0.05$) following a standard cycle warm-up along with 10 minutes BS (Bradley et al., 2007). Nelson and Kokkonen (2001) also found that BS reduced maximal muscle strength in the knee extension and flexion (A. Nelson & Kokkonen, 2001). Therefore, BS has not been widely supported in the literature to be a component of a warm-up.

PNF Stretching

PNF stretching, defined as a combination of passive stretch and isometric contractions of the target muscle, is often utilized to increase the joint ROM, muscular strengthen, and neuromuscular control by a therapist in clinical and rehabilitation environment (Marek et al., 2005). Weng et al (2009) found that PNF stretching was more effective on muscle strength than SS following isokinetic muscle strengthen exercises in 132 patients with knee osteoarthritis (Weng et al., 2009). However, Bradley et al (2007) demonstrated that PNF stretching decreased muscular performance. They found that vertical jump performance was diminished (5.1%) for 15 minutes following a standard cycle warm-up along with PNF stretching (Bradley et al., 2007). Thus, it is suggested that PNF stretching should not be performed immediately prior to an explosive movement in the physical activity.

Static Stretching

Static stretching is described as gradually lengthen a muscle to an elongated position as tolerated and that position is then held for a particular length of time to a point of discomfort (De Vries, 1962). Traditionally, it had generally been believed that SS increased the joint ROM, enhanced muscular performance, and prevent injury (Bandy et al., 1998; O'Sullivan, Murray, & Sainsbury, 2009; Power et al., 2004; Smith, 1994; W. B. Young & Behm, 2002). However, recent studies have demonstrated that SS reduced force, strength and power production, thus decreased performance

(Chaouachi et al., 2008; Faigenbaum et al., 2005; McNeal & Sands, 2003). These performance included isometric muscular contraction, sprint, and jump performance. Fowles et al (2000) found that isometric muscular strength in the ankle plantarflexors has been decreased for up to 1 h after performing 13 static dorsiflexion stretches of 135 s each over 33 minutes in ten young adults. This was interpreted by Kubo et al (2001) who indicated that tendon structure and connective tissue were inclined to be more compliant and muscle force was prone to be slack following SS, which led to a lower rate of force production (Kubo, Kanehisa, Kawakami, & Fukunaga, 2001). In addition, vertical jump performances diminished followed by SS in the hip and knee extensors for 100 s (Cornwell, Nelson, Heise, & Sidaway, 2001). The reason behind this could be that a decrease rate occurred in neural transmission with SS and thus caused a delay in muscle contraction velocity (Knudson, Bennett, Corn, Leick, & Smith, 2001). Furthermore, Fletcher and Anness (2007) found that 50-m sprint performance decreased followed by 800-m jogged warm-up alone with SS compared with active DS in eighteen experienced sprinters (Fletcher & Anness, 2007). This could be illustrated that a decreased ability in the musculotendinous unit (MTU) happened after SS, and then lead to a decrease level in muscle activation and force production (Cornwell, Nelson, Heise, & Sidaway, 2001). One study combined running and jump performance following SS. Faigenbaum et al (2005) compared the acute effects of 3 different warm-up protocols (5 minutes of walking with 5 minutes of SS, 10 minutes of DS, and 10 minutes of DS plus 3 drop jumps from 15-cm boxes). They found that long-jump, vertical-jump and shuttle-run performance reduced significantly ($p < 0.05$) following SS (Faigenbaum et al., 2005).

Since it has been questioned the wisdom of SS on muscular performance, it is suggested that SS should be avoided as a component of warm-up session.

Dynamic Stretching

Dynamic stretching is defined as a controlled movement through the joint active range of motion while moving but not exceeding individual's extensibility limits (Fletcher & Jones, 2004). The objective of DS is to increase dynamic flexibility in the target muscle by contracting the antagonist muscle without bouncing (Yamaguchi & Ishii, 2005). DS has increasingly gained popularity due to a number of studies showing an increase in high intensity performance in the joint ROM, leg power output, jump, running, sprint, and agility (Fletcher, 2010; Fletcher & Anness, 2007; Little & Williams, 2006; McMillian et al., 2006; Ranna & Koslow, 1984; Thompsen et al., 2007; Yamaguchi & Ishii, 2005; Yamaguchi et al., 2007).

Previous study showed that the gain of DS and SS on the ROM was almost identical. Ranna and Koslow (1984) compared the effects of SS, DS and PNF stretching on the ROM of hamstring-gastrocnemius muscles. The findings indicated that all three stretches produced significant improvement ($p < 0.001$) in the ROM during the pretest and posttest. No difference was found between all three stretches condition (Ranna & Koslow, 1984). This was agreed with Herman &Smith (2008)'s finding (Herman & Smith, 2008).

However, O'Sullivan et al's (2009) questioned the previous finding. They investigated the short-term effects of a general warm-up, SS and DS on the hamstrings ROM following assessing passive knee extension test in individuals with previous hamstrings injury and uninjured controls. It found that passive knee extension ROM significantly increased after a general warm-up ($p < 0.001$), further significantly increased ($p = 0.04$) after SS, while significantly decreased after DS ($p = 0.013$). The increased ROM after warm-up and SS reduced significantly ($p < 0.001$) after 15 minutes rest and further remained significantly greater than that at baseline ($p < 0.001$). The results of this study indicated that the effect of a general warm-up and SS on ROM was greater in those with hamstrings injured individuals, but not in DS (O'Sullivan et al., 2009). Therefore, the effect of DS on hamstrings flexibility or ROM was conflict.

Dynamic stretching has been demonstrated to increase muscular power output (Yamaguchi & Ishii, 2005; Yamaguchi et al., 2007). Yamaguchi and his colleagues worked on two studies related to leg power output. For their first study, under various loads at 5%, 30%, and 60% maximum voluntary contractile (MVC) torque with isometric leg extension, DS group was significantly ($p < 0.05$) greater than that in the no-stretching (NS) condition under each load (5% MVC: 468.4 ± 102.6 W vs. 430.1 ± 73.0 W; 30% MVC: 520.4 ± 108.5 W vs. 491.0 ± 93.0 W; 60% MVC: 487.1 ± 100.6 W vs. 450.8 ± 83.7 W) (Yamaguchi et al., 2007). Another study that measured leg extension power before and after stretches protocols (DS, SS, and NS) was consistent with above finding. DS and SS protocols focused on five lower limbs muscle groups, which were plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps femoris. DS group was significantly ($0 < 0.01$) greater than that in the SS group

(2022.3 ± 121.0 W). No significant difference was found between SS (1788.5 ± 85.7 W) and NS (1784.8 ± 108.4 W) condition (Yamaguchi & Ishii, 2005). Yamaguchi and his colleagues mentioned that post-activation potentiation (PAP) caused by voluntary contractions of the antagonist of the target muscle was the possible reason behind DS increased leg power output. Since PAP shortened the time to peak torque and increased the rate of torque development followed DS.

Besides the benefits in the power output, it has also been proven that DS increased running, sprint, agility, and jump performance (Fletcher, 2010; Fletcher & Anness, 2007; Little & Williams, 2006). Little and Williams (2006) found that DS (1.87 ± 0.09) produced a significantly ($p < 0.005$) faster 10-m sprint acceleration time than NS conditions (1.83 ± 0.08 seconds) and significantly ($p < 0.005$) faster Zig-zag agility performance (5.14 ± 0.17 seconds) than both SS (5.20 ± 0.16 seconds) and NS groups (5.22 ± 0.18 seconds). This study informed professional soccer player that DS was most effective as preparation for the subsequent high-speed performance (Little & Williams, 2006). Similarly, Fletcher and Anness (2007) notified that active DS significantly (men $p = 0.002$; women $p = 0.043$) decreased 50-m sprint time in experienced sprinters (Fletcher & Anness, 2007).

One study compared the effects of different DS velocities on jump performance. Fetcher (2010) found that faster velocity of DS (100 b/min) had a significant ($p < 0.001$) greater in all three jump performance, square jump (SJ), drop jump (DJ), and countermovement jump (CMJ) than both in the slow velocity of DS (50 b/min) and NS condition, and slow DS also resulted in significant ($p<0.001$)

greater performance in the DJ and SJ than NS condition. The mechanisms behind this were related to increases in heart rate and core temperature, and also linked to greater nervous system activation, shown by gastrocnemius in the CMJ significant higher in EMG output($p<0.005$) followed fast DS(Fletcher, 2010).

Given that the BS, PNF stretching, and SS resulted detrimental effects in muscular performance and thus may increase the incidence of injury, coaches, athletic trainers, fitness professionals therefore increasingly suggest that individuals should turn to a designed DS as a component of an effective warm-up due to its higher benefits on muscular performance (McMillian et al., 2006; Yamaguchi & Ishii, 2005).

Physiological Mechanisms Relating to Dynamic Stretching

Several physiological mechanisms that could explain the advantages of DS on muscular performance included increased core body and muscle temperature, alteration in musculotendinous unit (MTU) stiffness, post-activation potentiation (PAP), and myotatic reflex.

Positive effects of DS could be resulted from increased core body and muscle temperature within warm-up process (Yamaguchi & Ishii, 2005). This led to stimulate peripheral blood flow and then enhanced muscle temperature (Smith, 1994), further resulted in an increase in the nerve receptor sensitivity and nerve impulse velocity, and then produce a more rapid rate of muscle contraction and power production (Faigenbaum et al. 2005).

Bishop (2003a) indicated that DS had the ability to alter MTU stiffness. MTU stiffness incorporating with muscles, tendon, and connective tissue contracts tightly to transmit internal muscle forces to the skeletal system (G. J. Wilson et al., 1994). Stiffer MTU was required for a faster transmission of muscular force to bones, then generating a forceful movement (Kubo, Kanehisa, & Fukunaga, 2001). This further led to favorable changes in the force-velocity relationship (Bishop, 2003a). However, a compliant MTU allowed less force rate of transmission during muscle contraction (Kokkonen et al, 1998), less able to store elastic energy (Fletcher & Jones, 2004), and increase the time of force transmission from the central nervous system (CNS) to the muscle skeletal system (Fowles, Sale, & MacDougall, 2000).

Post-activation potentiation (PAP) is defined as the process when the contractile history of muscle holds a role in subsequent muscle contraction (Bishop 2003). This meant that a heavier loading applied to muscle prior to an explosive movement could cause a higher stimulation of the CNS to allow a forceful muscle contraction immediately (Chiu et al., 2003). Thus, PAP resulted in more rapid or forceful muscle contraction, and shortened the time to peak torque and increases the rate of torque development following DS (Fowles et al., 2000; Yamaguchi et al., 2007).

Myotatic reflex is defined as muscle contraction in response to stretching within the muscle. It has been proven that faster stretching speed could cause to greater action potential of the myotatic reflex (Gollhofer & Rapp, 1993; Gottlieb & Agarwal, 1979). Fletcher (2010) demonstrated that faster velocity of DS had significantly faster take-off velocity and vertical jump performance than the slower velocity of DS (Fletcher, 2010).

Although these possible physiological mechanisms provided basic evidence for DS linked to muscular performance, future research is still required to better illustrate high intensity muscular performance behind DS.

Static Balance and Dynamic Balance

In biomechanics, balance is defined as the ability to maintain the individual's center of gravity within their base of support with minimal postural sway (Shumway-Cook et al., 1988). Balance can separate into static balance and dynamic balance (Winter, Patla, & Frank, 1990). Static balance is defined as individual maintaining a stable base of support while minimizing segment and body movement (Bressel et al., 2007). Several valid measurements or clinical scales, such as a force platform, the Balance Error Scoring System (BESS) or Berg Balance Scale (BBS), can be used to measure static balance (P. Gribble et al., 2007). Although static balance provide useful clinical information or research outcome, the underlying task of standing as still as possible, such as postural sway, might not translate necessarily to movement tasks. Dynamic balance is defined as individual performing expected movement around a base of support to a new location and immediately attempting to remain as motionless as possible. Dynamic balance measurements, such as Star Excursion Balance Test (SEBT), or wobble board, more closely mimic demands of physical activity than static balance assessments (P. A. Gribble et al., 2012). Since many training exercise or sports competition requires both types of balance skills, it should incorporate static balance and dynamic balance together within exercise or research.

Two studies compared static and dynamic balance that was relatively relevant to the current designed study. Bressel et al (2007) compared static and dynamic balance among collegiate athletes competing in soccer, basketball, and gymnastics. BESS was used to assess static balance. Participants performed 3 stance variations (double leg, single leg, and tandem leg) on 2 surfaces (stiff and compliant). SEBT was used to assess dynamic balance. Participants performed multidirectional maximal single-leg reaches from a unilateral base of support. It found that BESS error scores for the gymnastics group were 55% lower than for the basketball group and SEBT scores were 7% higher in the soccer group than the basketball group. The results of this study indicated that gymnasts and soccer players did not differ in terms of static and dynamic balance. In contrast, basketball players displayed inferior static balance compared with gymnasts and inferior dynamic balance compared with soccer players (Bressel et al., 2007). Similarly, Ross & Guskiewicz (2004) determined static and dynamic postural stability differences with functional ankle instability individuals. A single leg stance for 20 seconds was used to measure static postural stability, while a single jump-landing test that required to jump 50% to 55% of participants' maximum vertical jump height and maintained motionless for 20 seconds after landing was used to assess dynamic postural stability. The results indicated that mean sway was not significantly different between groups in the anterior/posterior ($P = 0.28$) and medial/lateral ($P = 0.65$) directions. The functional ankle instability group took significantly longer to stabilize in the anterior/posterior (3.27 ± 0.72 seconds vs. 2.33 ± 0.33 seconds; $P < 0.001$) and medial/lateral (2.48 ± 0.50 seconds vs. 2.00 ± 0.65

seconds; P = 0.04) directions. It came to a conclusion that individuals with functional ankle instability took significantly longer to stabilize than individuals with stable ankles after a single-leg jump landing, while there was no difference between groups with mean sway measured during single-leg stance (Ross & Guskiewicz, 2004).

Based on different static balance measurement evaluated above, it is therefore necessary to examine the effects of static balance through a more sensitive and reliable tool.

Time-to-Boundary

Postural control is the specific terminology describing static balance. Postural control plays an important role not only in the injury prevention, but also in the athletic performance. Increased postural control is generally linked with increased risk of falling with neurological impairment (Matinolli et al., 2007), unstable ability in dynamic tasks (Latash, Ferreira, Wieczorek, & Duarte, 2003), and with higher risk for ankle sprains (McGuine et al., 2000).

Traditionally, maintaining postural control is defined as the amount of postural sway of the center of mass (COM) or center of pressure (COP) to return the center of gravity to a centralized position over the base of support (Rietdyk, Patla, Winter, Ishac, & Little, 1999). The postural sway measures the frequency against time by assessing medial-lateral and anterior-posterior displacement of the center of pressure (Patla, 1990; Winter et al., 1990). A small amount of COM or COP excursion is considered as more stable than a larger amount of COM or COP excursion (Woollacott, Shumway-Cook, & Nashner, 1986).

Time-to-boundary (TTB) provides a novel postural control approach to assess static balance. TTB is defined as estimating the time it would take for the COP to reach the boundary of the base of support if the COP was to continue on its trajectory at its instantaneous velocity (Hertel & Olmsted-Kramer, 2007). A lower TTB outcome indicates greater postural instability since the COP is closer in time to reaching the boundary of the base of support (van Emmerik & van Wegen, 2002). TTB measures have been shown to have intrasession reliability with intraclass correlation coefficients ranging from .34 to .87 (Hertel, Olmsted-Kramer, & Challis, 2006). TTB measures can assess COP excursions in relation to the boundaries of the base of stability that is not addressed by traditional postural control measures. TTB has been proven to be more sensitive at detecting improvements in static postural control compared with summary COP-based measures (Mckeon et al., 2008), and as well as in detecting postural control deficits associated with CAI than traditional postural control measures (Hertel & Olmsted-Kramer, 2007). Therefore, TTB measures were used in this study rather than traditional postural sway measurement.

Star Excursion Balance Test

The star excursion balance test (SEBT) is a clinical technique to measure dynamic balance during rehabilitation, injury evaluation, and research applications (Hertel et al., 2000; Kinzey & Armstrong, 1998). SEBT has been proven to not only an easy-to-use outcome tool to measure dynamic balance in research, but also a clinical application to predict the risk of injury to lower extremity (Plisky et al., 2006). The SEBT usually consists of a series of lower extremity reaching tasks in 8 directions (anterior, anteromedial, anterolateral, medial, lateral, posterior, posteromedial, and posterolateral) from the center of grid that require individual's postural control, strength, range of motion, coordination and proprioceptive abilities. The farther distance the touching leg reaches, the better dynamic balance it displays. The ability to reach farther with the touching leg also requires a combination ability of better dynamic balance on the contralateral stance leg (Hertel et al., 2000). Hertel et al (2006) simplified the SEBT that using three reach directions (anterior, posteromedial, and posterolateral) to identify individuals with CAI (Hertel, Braham, et al., 2006) . The SEBT has a strong intratester and intertester reliability. The intraclass correlation coefficients was ranging from .85 to .96 for intratester reliability and from .81 to .93 for intertester reliability (Hertel et al., 2000; Kinzey & Armstrong, 1998).

Factors Contributing to SEBT Performance

To make valid comparisons of SEBT, reaching distances need to be normalized to individual's limb length as measured from the anterosuperior iliac spine to the medial malleolus (P. A. Gribble & Hertel, 2003). Besides limb length, several other anthropometric and physiologic factors including ROM, fatigue, and interventions also potentially contributed to SEBT performance.

Range of Motion

Dorsiflexion range of motion in the ankle was correlated strongly with anterior reaching distance in the SEBT. Hoch et al (2011) examined the relationships between maximum dorsiflexion range of motion on the weight-bearing lunge test (WBLT) and normalized reach distance in three directions (anterior, posteromedial, and posterolateral) on the SEBT. Thirty-five healthy adults performed three trials of the SEBT in three directions on each limb to assess dynamic balance, and then three trials of the WBLT to measure maximum dorsiflexion range of motion. It found that only the anterior direction (79.0 ± 5.8%) of the SEBT was significantly related to the WBLT (11.9 ± 2.7 cm), $r = 0.53$ ($p = 0.001$). The WBLT explained 28% of the variance in the anterior normalized reach distance ($r^2 = .28$). This results indicated that the anterior direction of the SEBT may be a desired clinical measure to assess the effects of maximum dorsiflexion range of motion on dynamic balance (M.C. Hoch et al., 2011).

There are 2 studies related to how kinematic factors (hip and knee flexion) can affect SEBT performance between participants with and without CAI. Gribble et al (2007) investigated the influence of CAI on the performance of SEBT after fatiguing protocol. Thirty subjects completed the SEBT before and after a lunging fatigue protocol. Pre-post fatigue change scores were measured for sagittal plane kinematics of the stance leg and the normalized reach distances. When reaching anteriorly after the lunge fatigue in CAI group, the changes in knee and hip flexion predicted approximately 49 % of the variance in normalized reach distances (R2 = .487; p = .001). When reaching medially under lunge fatigue in CAI group, the changes in knee and hip flexion predicted approximately 20 % of the variance in normalized reach distances (R2 = .198; p = .014). The results indicated that CAI significantly affected the variances in normalized reach distances after a fatigue protocol (P. Gribble et al., 2007). In another similar designed study, Gribble et al (2004) found that the injured side of the CAI subjects displayed significantly smaller reach distance values and knee flexion angles for all 3 reaching directions compared with the uninjured side and the healthy group (P. A. Gribble et al., 2004). With 2 studies, the differences of kinematic pattern in the knee and hip of the sagittal plane after performing the SEBT suggest that those who with CAI was associated with a reduction in dynamic balance.

Given that the interference with dorsiflexion in the ankle, knee flexion and hip flexion in the sagittal plane on the SEBT, this information might be helpful for clinicians to design specific rehabilitation protocol for patients with dynamic postural control impairments.

Fatigue

It is widely accepted that fatigue can affect physical performance. Gribble et al (2009) examined the effects of fatigue on performance measures of the SEBT in three directions (anterior, posteromedial, and posterolateral).16 healthy young adults performed the SEBT before and after 4 different fatiguing conditions (isometrically applied fatigue to the ankle, knee, and hip and continuous lunging). The normalized reach distances and sagittal-plane kinematics of the knee and hip were recorded. It found that fatigue produced deficits in normalized reach distances and decreased knee flexion in all 3 reaching directions (P. A. Gribble, Robinson, Hertel, & Denegar, 2009). This was consistent with previous two studies, Gribble et al (2004) and Gribble et al (2007) that suggest that SEBT performance might provide a useful approach for assessing decline in dynamic balance from fatigue.

Interventions

Some studies have examined the effects of SEBT on improvements in performance and reduce the risk of injury after designed exercise interventions as an outcome tool, including balance training, core stability training, and neuromuscular control exercise programs (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010; FitzgeralD, Trakarnratanakul, Smyth, & Caulfield, 2010; Hale, Hertel, & Olmsted-Kramer, 2007; Mckeon et al., 2008).

Mckeon et al (2008) investigated the effect of a 4 week balance training program on static and dynamic postural control in those with CAI. The intervention consisted of a 4 week supervised balance training program that emphasized dynamic stabilization in single-limb stance. They found that the balance training group had significant improvements in reach distances with the posteromedial ($P = .01$) and the posterolateral ($P = .03$) directions of the SEBT (Mckeon et al., 2008). Similarly, Hale et al (2007) also found differences in the posteromedial ($P = .03$), posterolateral ($P = .01$) reach directions of the SEBT and a composite score of all 8 directions ($P = .03$) following a 4 week intervention of strength, ROM, and neuromuscular control exercises in those who with CAI (Hale et al., 2007).

Kahle and Gribble (2009) focused on a 6 week intervention training program in healthy and physically active young adults. They found that the exercise group improved their scores by more than 4 % ($P= .001$) in the anteromedial direction and improved 6% from baseline and was more than 6% better than the control group in the medial direction with moderate to strong effect sizes (Kahle & Gribble, 2009).

Fitzgerald et al (2010) revealed improvements of 2.95% to 9.4% in the anterior, posteromedial, and posterolateral reach directions of SEBT after 12 exercise sessions of wobble board or postural stability training. Similarly, Filipa et al (2010) found that 8 weeks of neuromuscular control training in young female athletes improved performance in the same 3 directions by 1.75% to 9.5%. Neuromuscular control training was provided by mostly moderate to strong effect sizes that ranged from 0.58 to 1.00 (Filipa et al., 2010; FitzgeralD et al., 2010).

Since stretching could affect alteration in ROM and neuromuscular control that has been associated with the SEBT, it is important to understand the relationship between stretching and the SEBT, namely dynamic balance.

Stretching and Balance

Balance is important for a wide of population, which includes recreationally active individuals, elite athletes, and elderly. For the recreationally active individuals and elite athletes, impaired balance affects optimal athletic performance, and even cause injury incidence. For the elderly, a balance deficit is prone to the higher risk of a fall, and then cause osteoporotic fractures (M. E. Nelson et al., 1994). Since balance plays an important role in the lifespan, it is critical to understand how physical interventions, especially stretching, affect it.

Performance

Several studies have focused on the relationship between SS and static or dynamic balance, but no research has concentrated on the effects of DS on either static or dynamic balance.

One study focused on the SS and joint position sense. Ghaffarinejad et al (2007) investigated the effect of SS in relation to muscle surrounding the knee on the knee joint position sense (JPS). JPS was measured through the absolute angular error (AAE) in order to estimate the ability to reach two target positions (20° and 45° of flexion) in the dominant knee. Thirty-nine healthy students was tested by three 30 s SS with a 30s rest. AAE values were measured repeated three times before and immediately after SS trials. They found that the AAE decreased significantly after the stretching protocols for quadriceps (3.5 (1.3) vs 0.7 (2.4); $p<0.001$), hamstring (3.6 (2.2) vs 1.6 (3.1); $p = 0.016$), and adductors (3.7 (2.8) vs 1.7 (2.4); $p = 0.016$) in 45° of flexion. The results suggest that the knee JPS improvement in 45° of flexion following SS was contributed to the knee joint stability. This was expected to improve balance since joint position sense was linked to proprioceptive response (Ghaffarinejad, Taghizadeh, & Mohammadi, 2007).

Three studies examined the effects of SS on dynamic balance, while using different dynamic balance measurements, stabilometer, Berg Balance Scale (BBS), and Dynamic Stability Index (DSI), but not the SEBT.

Costa et al (2009) evaluated the effects of different durations of SS on dynamic balance. The SS protocols consisted of a cycle ergometer warm-up at 70 rpm and 70 W followed by SS (passive unilateral knee flexion, supine hip flexion, ankle dorsiflexion with an extended knee, and ankle dorsiflexion with a flexed knee) on the target muscle groups (quadriceps, hamstring, and plantar flexor). Each stretching repeated 3 times with 15 seconds rest of periods and the positions were held for 15 or

45 seconds to the point of mild discomfort. The control one consisted of the same cycle ergometer warm-up with a 26-minute rest of period between pretests and posttests. Dynamic balance was measured using the BBS which was similar to actual physical activities that resulted in instability. They found that the balance scores were significantly improved ($p<0.01$) in the 15-s stretching condition and no significant was found in the 45 s stretching condition. The results of this study indicated that SS of 45 s did not adversely affect dynamic balance and SS with 15-second may improve dynamic balance (P.B. Costa et al., 2009).

Similarly, Handrakis et al (2010) tested ten middle-age subjects (age: 40-60 yr.) from a martial arts school following 10 minutes SS with 30 seconds hold for session. Dynamic Stability Index (DSI) was used to test dynamic balance for single-leg stance. Smaller DSI meant improved dynamic balance while greater DSI indicated opposite effect. Other dependent variables included distances for broad jump, single hop, triple hop, and crossover hop; elapsed time for a 6-m timed hop. They found that DSI of SS group was significantly smaller than that in the NS group (3.5 ± 0.7 vs. 4.3 ± 1.4 DSI, $p < 0.05$). No significant difference was found in the other dependent variables in both two groups. Thus, it came to a conclusion that 10 minutes of acute SS with 30seconds hold enhanced dynamic balance in active middle-aged adults.(Handrakis et al., 2010).

In comparison with non-balance trained individuals with experienced balance trainers, Nelson et al (2011) investigated the effects of SS on postural stability in forty-two college students and ten surfers performed balance testing on a stabilometer on two separate days following either 30 min of quiet sitting or 30 min of SS protocols. For the dynamic balance, the average time of keeping on the stabilometer was recorded at 180° for two 30s periods. For the stretching protocol, it consisted of five different SS exercises (sit-and reach, stretch, the lotus or butterfly stretch, the heel cord or calf stretch, a standing half lotus stretch, and a quadriceps stretch) for 3 times unassisted and 3 time assisted to the muscles groups of the hip, knee, and ankle. The results indicated that improved flexibility was significant ($p<.05$) following the SS protocols for increasing (6.5 ± 2.7 cm) in sit and reach test. In addition, balance time for non-balance trained individuals also improved significantly by 11.4% (2.0s increase), but no significant change in the surfers. Thus, SS improved maintenance of dynamic balance for non-balance trained individuals, but not for the experienced balance trainers (A. G. Nelson et al., 2011).

Besides research on the relationship between SS and dynamic balance, three studies examined the effects of SS on static balance using a wobble board and postural sway, respectively, but not related to TTB.

Behm et al (2004) evaluated the effect of an acute SS on static balance, force, proprioception, reaction time and movement time. Sixteen subjects were tested before and after both with a SS of the quadriceps, hamstring, and plantar flexors or a similar duration in the control condition. The stretching protocol consisted of a 5-min cycle warm-up followed three stretches to the point of discomfort of 45s each with 15s rest. SS included a series of unilateral knee flexion, hip flexion with extended leg in the supine position, extended leg dorsiflexion in the standing position, and flexed knee dorsiflexion in the standing position. Measurements included maximal voluntary isometric contraction (MVC) force of the leg extensors, static balance using a wobble board, reaction and movement time of the dominant lower limb. They found that there was a significant (P < 0.009) decrease in balance scores with the SS condition (decreasing for 9.2%) compared with the control condition (increasing for 17.3%). There was significant difference (P< 0.01) in reaction (decreasing for 5.8%) and movement (decreasing for 5.7%) time in the control condition and (increasing for 4.0% and 1.9%) in the SS condition The results indicated that an acute SS adversely affect performance on static balance and reaction/movement time (Behm et al., 2004).

The finding of Behm et al (2004) was supported by Nagano et al (2006)'s study, which evaluated the effects of vision and SS of the calf muscles on postural sway during quiet standing. Participants first stood on a force plate in 30 s for both legs and the postural sway of the ground reaction force COP was recorded. Participants then stood quietly on a device incorporating a static ankle joint dorsiflexion stretching in 3 min. After that, postural sway was recorded again. The findings of this study indicated that postural sway significantly increased after SS in the dependent variables: sweep speed, sway speed, standard deviation, maximal anteroposterior range, mean anteroposterior position (Nagano et al., 2006).

Similarly, Lewis et al (2009) investigated the effect of SS on postural sway and on the kinematic variables in gender. SS and NS groups were tested separately prior to balance testing with electromyographic (EMG) recordings of muscle responses. In the SS protocol, the quadriceps, hamstring, and plantar flexors of bilateral were passively stretched in the supine position with three 45 s and a 15 s rest of period.

Testing during the NS condition began after the subject rested quietly for an equivalent period of time as in the SS condition. Balance testing included the Postural Evoked Response Test, Adaptation Test, Motor Control Test, Sensory Organization Test, and Unilateral Stance Test. They found that no significant main effect for SS and 2 significant main effects for gender for the Motor Control Test ($P = 0.021$) and latency of tibialis anterior ($P = 0.009$). The results indicated SS did not affect balance performance during computerized dynamic posturography both for women and men (Lewis et al., 2009).

Since many physical activity and rehabilitation interventions requires both types of balance (static and dynamic), it would be therefore advantageous to incorporate static and dynamic balance task together when investigating the effect of SS on performance in an integrated research. In addition, it is also important to understand how DS would affect on static or dynamic balance since no research has focused on it.

Mechanism

Keeping balance is described as the ability to maintain the base of support with minimal movement (Winter et al., 1990). A complex nervous system with automatic postural responses, volitional motor control and reflexive responses controls the ability of balance (Bloem, Allum, Carpenter, & Honegger, 2000; Shiratori & Latash, 2000). This integrated system or mechanism is adjusted mainly by the CNS as expressing self-promoted postural perturbations (Aruin, Forrest, & Latash, 1998), and also influence individual’s movement in the ability of coordination, ROM, muscle strength, and power production (Grigg, 1994; L. Nashner, 1976; R. M. Palmieri et al., 2003; R. Palmieri, Ingersoll, Stone, & Krause, 2002). If function of physiological mechanism were changed, the performance of balance would be affected, and may further increase the risk of a fall or injury.

One possible physiological mechanism that affects the ability and performance of balance in relation to stretching could be proprioception. Proprioception is one of contributors to control postural stability (Di Giulio et al., 2009). Proprioception is composed of sense from sensory neurons in the inner ear and in the stretch receptors in the muscles and the joint ligaments. Proprioceptive sense originating from joint and muscle receptors plays an integral role in the aimed at preparing, maintaining, and restoring stability of postural stability of entire body and the joint stability of the segments (Riemann & Lephart, 2002). It is possible that a small change in the activity of a proprioceptor, it could lead to a greater change in balance (Diener et al., 1984). Proprioceptors affect postural stability through the stretch-reflex response (L. M. Nashner, 1981), which sensitivity could be influenced by muscle stiffness, with stiffer muscles producing a greater reflex response (Sinkjaer et al., 1988). This was possible due to the postural control maintained by stiffer muscles through greater or more rapid responses to slight perturbations in muscle length (Petit et al., 1990). Since stretching has ability to change the muscle stiffness, muscle length, and increase joint ROM, it is reasonable to postulate that stretching could affect function of balance (Behm et al., 2004; Chong & Do, 2002; McHugh & Cosgrave, 2009).

Summary

Since SS has been doubted its effectiveness on performance and injury prevention, DS has been widely accepted to be a component of a warm-up due to its benefits on muscular performance. In addition, as reliable measure of dynamic balance, SEBT could be influenced by ROM, fatigue, and balancing training and neuromuscular control interventions, however, it is still unclear the effects of SS and DS on the SEBT, and the relationship of the SEBT on static balance. Moreover, proprioceptors are sensitive to muscle tension and length, it is therefore reasonable to postulate that stretching could affect balance. Few studies have focused on the relationship between SS and static or dynamic balance, and no research has concentrated on the effects of DS on either static or dynamic balance. This study will provide basic scientific evidence and clinical application for informing future research that focus on lower extremity muscular performance, injury prevention, and rehabilitation with regard to altered ROM, balance, and stretching.

CHAPTER 3: METHODS

Purpose

The purpose of this study was to examine the effects of static and dynamic stretching on lower extremity joint ROM, static balance, and dynamic balance.

Participants

Participants were recruited by informational flyers posted at University of Wisconsin-Milwaukee. The flyers provided the contact information of the investigator and a brief description of the study including the purpose, and the criteria for inclusion and exclusion. Classroom visits were made to contact potential participants who may be interested in participating. These visits met the guidelines of Institutional Review Board. Both males and females between age of 18 and 45 were eligible for the study.

The inclusion criteria of the participant was that the individual was: 1) male or female between the age of 18-45, and 2) recreationally active (engage in some form of physical activity at least 30mins and 3-4 days per week) (A. G. Nelson et al., 2011). To maximize the potential effects of the stretching protocols, individuals who demonstrate muscular tightness in the gastrocnemius/soleus and hamstring muscles formed the study sample. The assessment procedures were described in the following "Protocol" section.

The exclusion criteria of the participant was that the individual was: 1) free from lower extremity pain or injury in the past 6 month or any other physical deficit that limited them in performing the balance testing and stretching protocols, 2) No history of concussion or balance disorders within the last 6 months, and 3) No history of participating in a proprioceptive or balance training activity in the past 6 months. Regardless of current level of physical activity, participants agreed not to change the intensity or frequency of physical activity during the testing session and refrain from them 24 hours prior to testing sessions.

Statistical power analysis based on previous studies (Bandy et al., 1997; R. Gajdosik & Lusin, 1983; Handrakis Bandy & Irion, 1994; Nagano et al., 2006) concluded that 15 participants would provide sufficient power for the analyses. All participants provided written informed consent prior to data collection.

Instrumentation

A fluid inclinometer was used to identify maximum hip flexion angle, and maximum knee extension angle in the Active Knee Extension (AKE) test.

A tape measure was used to measure the furthest distance between the great toe and the wall in the weight-bearing lung test, an assessment of dorsiflexion ROM. A light dowel was used for the Deep Squat (DS) test.

The time-to-boundary (TTB) was assessed by an AMTI force plate (Model OR-6-7-2000, Advanced Mechanical Technology, Inc, Watertown, MA) at a sampling rate of 100 Hz to measure the functional performance of static balance. A written program (Matlab, v. 7.6.0, The MathWorks Inc, Natick, MA) was used to compute a time series of time-to-boundary. Triaxial forces (Fx, Fy, Fz) and moments (Mx, My, Mz) was recorded at 100 Hz and a time series of 500 Center of Pressure (COP) data points for each trial was calculated by the Swaywin1 software program

(AMTI Corp., Watertown, MA).

Dynamic balance was assessed using the Star Excursion Balance Test (SEBT). The testing grid consisted of 3 lines, each 120 cm in length extending to anterior, posteromedial, and posterolateral direction in relation to the stance foot. Standard athletic tape placed on the surface of grid. The center of the grid was marked with crosshairs that participants were instructed to stand in the center of the grid during testing (Hertel, Braham, et al., 2006).

A treadmill was used for a general warm-up. The University of Wisconsin-Milwaukee Neuromechanics laboratory provided space for participants to perform stretching interventions.

Protocol

All of the study activities took place at the University of Wisconsin-Milwaukee Neuromechanics Laboratory. A general testing protocol overview is provided below in Figure.1.

Orientation Session (1 hour)

1. Explanation of the concept of the study and fill out paperwork
2. Screening tests: AKE test and DS test
3. Range of motion test (dorsiflexion, knee extension, hip flexion)
4. Orientation of the procedures
    1) Balance testing (TTB and SEBT)
    2) Warm-up protocols

Testing Session 1-3 (1 hour)

Repeated Measures Test

1. Balance testing (TTB and SEBT)
2. Warm-up protocols (counterbalanced within participants)
    3) 5 minutes general warm-up with dynamic stretches
    4) 5 minutes general warm-up with static stretches
    5) 5 minutes general warm-up alone
3. Balance testing (TTB and SEBT)
4. Range of motion test (dorsiflexion, knee extension, hip flexion)

Fig.1: Testing protocols flow-chart.

Orientation Session

The purpose of the orientation session was to educate the participants to better understand the process of the study, to eliminate the possibility of a learning effect that could confound the balance testing following the interventions, and to test their baseline of range of motion angles. All participants were provided a clear explanation of the brief concept of the study, the procedure, time requirement, compensation and risks of the study prior to the data collection. Participants were also familiarized with the laboratory environment, the investigator and any other laboratory researchers who assisted in the study. All testing procedures were approved by the University of

Wisconsin-Milwaukee's Institutional Review Board prior to conducting the study, and after the participant providing consent the testing began.

Participants were asked to continue their regular physical activity but refrain from them the day before testing. Questionnaires (Appendix C) were completed by all participants to assess their current level of physical activity, injury, balance disorders and surgery history. Additional anthropometric data including leg length (from the anterior superior iliac spine to the distal tip of the medial malleolus), height, weight and age was also collected.

Range of Motion Tests

The participant's tested leg, defined as the tighter hamstring leg in the screening session, was measured throughout the study (ROM and Balance tests). The range of motion tests that include ankle dorsiflexion via the weight-bearing lunge test (WBLT) with barefoot, knee extension via the active knee extension (AKE) test, and hip flexion via active hip flexion in a supine position were tested before and after each of intervention (knee extension, hip flexion, and ankle dorsiflexion). Three trials of each test were performed and the mean value was used for data analysis. No warm-up was allowed prior to the tests and the same investigator made all ROM measurements throughout the study.

Weight-bearing Lunge Test

Participants performed the weight-bearing lung test (WBLT) to assess their maximal dorsiflexion range of motion, based on the Vicenzino et al (2006) study. Participants were barefoot in a standing position keeping the second toe, center of the heel, and knee in the sagittal plane, while planting the test heel firmly on the floor and flexing their knee to touch the wall. The opposite leg was used to maintain stability behind the test leg (Figure.2). Participants then lunged forward until their knee touches the wall. The stance foot was then incrementally moved away from the wall until maximal dorsiflexion, which was defined as the furthest distance between the great toe and the wall without the heel lifting off the ground and the knee still touching the wall, is reached. The investigator used a tape-measure the furthest distance (Vicenzino, Branjerdporn, Teys, & Jordan, 2006).

Fig.2: Participants positioning for the weight-bearing lung test.

Active Knee Extension Test

Active Knee Extension (AKE) test was used both for screening the hamstrings tightness and measuring knee extension degree, based on Kuilart et al (2005) study. The reliability of AKE test has been previously demonstrated to be excellent (R. Gajdosik & Lusin, 1983). Participants were in supine position with left hip flexion in 0°, maintained by a Velcro strap secured to the table (Figure.3).

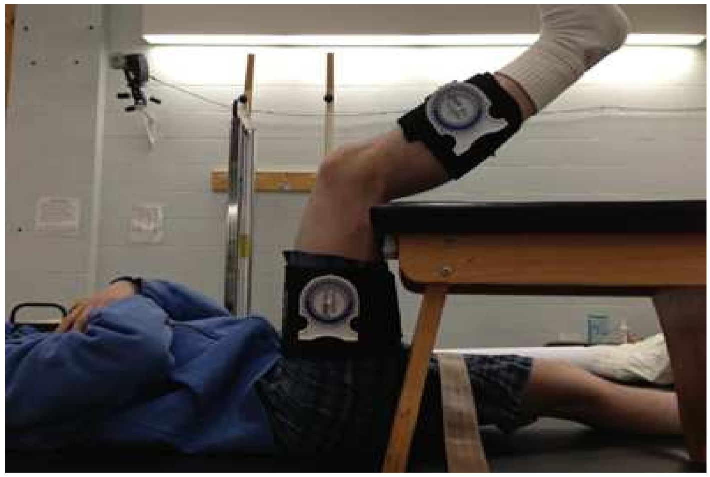

Fig.3: The angle was greater than 15° or more from the vertical position indicated tight hamstrings and was a criterion for inclusion.

The participants first flexed the right thigh in 90°, with the right ischial tuberosity placed against the box. The right mid-thigh was maintained by a Velcro strap secured to the box as well. Participants were then instructed to slowly extend their tested knee with the foot relaxed in plantar flexion to their terminal position, defined as the point at which the participants complain of a feeling of discomfort or tightness in the hamstring muscles or the investigator perceived resistance to stretch. Zero degree of knee extension from the vertical position was considered complete knee extension and full hamstring muscle flexibility. The measured angle greater than 15° from the vertical position met the inclusion criterion of hamstring tightness (Kuilart, Woollam, Barling, & Lucas, 2005). The angle from vertical was recorded in degrees, and used for analysis. The intra-class correlation coefficient was calculated in the Kuilart et al (2005) study, which suggested excellent intra-tester reliability (ICC 0.99, 95% CI 0.99-1.00), and pilot testing confirmed the reliability of the primary investigator.

Hip Flexion Test

Participants were in the supine position. Pelvic movement was restricted by a strap firmly across the contralateral distal thigh. A fluid inclinometer was attached to a strap around the thigh of the test leg, and zeroed with the leg in a horizontal resting position. The participant then flexed the hip as far as possible with the knee in flexion, until a firm end feel is reached (Figure.4). Hip flexion angle was then measured by the inclinometer relative to the horizontal plane. (Pua, Wrigley, Wrigley, Cowan, & Bennell, 2008).

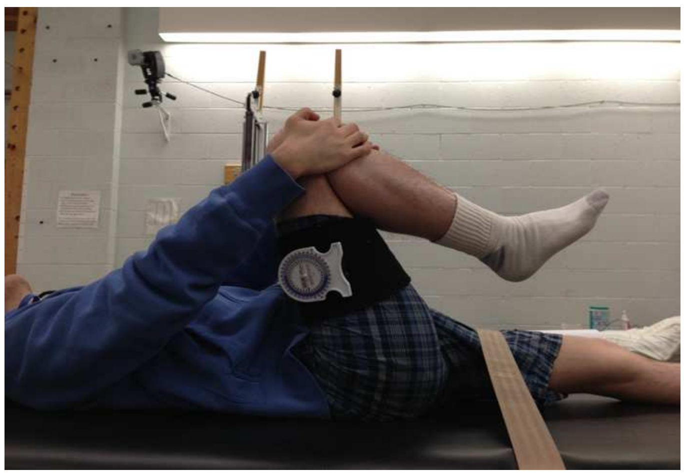

Fig.4: Participants positioning for the hip flexion test

Deep Squat Test

Participants first stood upright with their feet shoulder width apart and with their feet facing forward, and wearing their own "athletic" style shoes. Participants were then asked to grab the dowel and press it over head with the feet shoulder width apart. Afterwards, participants were instructed to squat down as low as they can while keeping their heels on the floors, and let their thighs drop below parallel with the floor and keep their knees over their toes. Participants were also instructed to keep the overhead dowel above their head thus keeping the trunk approximately parallel with the angle of the tibia (Figure.5). Participants who can successfully squat down so that their thighs fall past horizontal while keeping their heels on the floor DO NOT have calf tightness, and were therefore excluded. Participants who cannot complete the deep squat as described DO have calf tightness and were included in the study (Butler, Plisky, Southers, Scoma, & Kiesel, 2010).

Fig.5: Deep squat test: participants squats down while keeping the dowel overhead and keeping the trunk approximately parallel with the angle of the tibia

Task Practice

The participants practiced the static balance test (TTB), dynamic balance test (SEBT), and stretching protocols (static stretching and dynamic stretching) during the orientation session.

Participants were instructed to practice all the balance testing and stretching protocols until they feel comfortable performing them. To minimize the learning effect of TTB, participants performed 3 practice trails in the single leg stance (30s) for the test leg with 1 minute rest of periods between each trail in the orientation session (A. G. Nelson et al., 2011). To minimize the learning effect of SEBT, each participant performed 6 practice trials in each of the 3 directions on the test leg with 1 minute rest of periods between each trail in the orientation session (Hertel et al., 2000).

Balance Testing

Participants wore shorts and laboratory sandals during the static balance test. A standardized sandal method was chosen because it has previously been used to assess static balance using the time-to-boundary method (Cobb, Joshi, Bazett-Jones, & Earl-Boehm, 2012). The Star Excursion Balance test was measured with participant's barefoot. Balance tests (TTB first, then SEBT) were measured before and after each of interventions (static stretching, dynamic stretching, control warm-up).

Time-to-Boundary

Time-to-Boundary was used to assess the static balance. Each participant performed three trails with 10s of single leg stance as still as possible with eyes closed on an AMTI force platform (Model OR-6-7-2000, Advanced Mechanical Technology, Inc, Watertown, MA) to collect ground reaction force data. For all three trials, the stance foot was meticulously placed in the same position on the force plate that has a detailed grid on its surface to allow for exact placement. The hands were kept on the waist, and the opposite leg will be flexed at the hip and knee to approximately 30°. The data collection began after the participant establishes a stable posture on the force platform. Data was recorded at 100Hz and the mean value of three trails was used for data analysis. If participants lose their balance and are unable to complete a trial, the trial will be repeated. A trial will also be repeated if participants open their eyes during the eye closed condition. Center of Pressure (COP) data was then filtered with a fourth order zero lag, low pass filter with a cutoff frequency of 5 Hz.

Star Excursion Balance Test

Star Excursion Balance Test (SEBT) was used to assess dynamic balance based on Hertel et al (2006) study. Athlete tape was placed on the floor to create a “Y” shaped pattern with 3 lines extending from the center. The 3 lines are named according to the direction of reach in relation to the stance leg: anterior, posteromedial, and posterolateral. A crosshairs was drawn at the center of the grid. The most distal aspect of the great toe was placed at the crosshairs in the center of the grid. Participants maintained a single-leg stance while the contralateral leg reaches to touch as far as possible along the each line. Participants touched the furthest point possible on the line with the most distal part of their reach foot. The reach foot touched the furthest point on the line as lightly as possible so that the reach leg did not provide considerable support in the maintenance of upright posture. If it is determined that the reach leg is used for support or the stable base of support is compromised, the trial will be performed again. Reach distance was marked with on the tape with a marker immediately after each trail. Participants then returned to a bilateral stance. The investigator manually measured the distance in millimeter from the center of the grid to the touch point with an athletic tape based on the mark. Reach distances were then normalized to participants' leg length (P. A. Gribble & Hertel, 2003). The order of reach directions were counterbalanced to avoid order effects from contaminating the data (Stevens, 2001).

Participants performed 3 trials in each direction and the mean value was used for data analysis. Ten seconds periods of rest was provided between each trial. Visual cues and objects on the floor and people in front of the participants were not allowed in the study to eliminate visual and auditory influences. No encouragement or further instruction was given to participants throughout the testing (Hertel, Braham, et al., 2006).

Warm-up Protocols

There were three warm-up interventions (a general warm-up with dynamic stretching, a general warm-up with static stretching, and a general warm-up alone). The order of target muscles (quadriceps, hamstrings, and plantar flexors) both for dynamic stretching and static stretching were randomized. The individual testing sessions occurred over a three to four week period, with at least 48, but no more than 96 hours between testing. The interventions were counterbalanced to prevent order bias and learning effect. An attempt was made to test all participants at the same time of day to be as consistent as possible. During each intervention participants wore their typical athletic type footwear.

A general warm-up

A general warm-up consisted of 5 minutes of light-jogging on a treadmill at self-selected comfortable pace was performed by participants before dynamic and static stretching interventions.

Dynamic Stretching

Dynamic stretching consisted of 4 repetitions of bilateral dynamic stretches of the quadriceps, hamstrings, and plantar flexors (4 repetitions in total x 3 muscle groups x two limbs) for 30s each and 20s periods of rest. The stretching protocols based on Behm et al (2011), but dynamic hamstring stretch has been modified to more directly focus on this muscle group. Participants were asked to achieve the highest range of motion possible for all dynamic stretches. A description of each dynamic stretch can be found in Table 1.

Table 1: Dynamic Stretching Protocol

Muscle group	**Body position**	**Movement**
Quadriceps	Standing	Walking “butt kicks” that causes dynamic knee flexion and hip extension
Hamstrings	Standing	Walking hip flexion with knee extended that causes the leg swinging up to the anterior aspect of the body
Plantar Flexors	Standing facing the wall, hands placed on the wall at shoulder height. Feet should be positioned far enough away from the way to elicit a stretching feeling in the calf muscles.	Push off or rebound from the wall to produce a dynamic stretch

Static Stretching

Static stretching consisted of 4 repetitions of static stretches for the right and left quadriceps, hamstrings, and plantar flexors (4 repetitions in total x 3 muscle groups x two limbs), holding at the point of discomfort for 30s each and 20s periods of rest (Behm et al., 2011). A description of each static stretch can be found in Table 2.

Table 2: Static Stretching Protocol

Muscle group	**Body position**	**Movement**
Quadriceps	Standing	Flex the knee with using their arm to pull the foot towards the buttocks as far as possible producing a stretching sensation.
Hamstrings	Standing	Flexing the hip and placing the heel on a 50 cm high platform, then reach forward with their arms towards the extended leg as far as possible producing a stretching sensation.
Plantar Flexors	Standing facing the wall, hands placed on the wall at shoulder height. Feet should be positioned far enough away from the way to elicit a stretching feeling in the calf muscles.	Leaning forward while keeping the feet flat on the floor as far as possible producing a stretching sensation.

Data Analysis

The threshold for ground reaction forces was set at 30N. The global and local coordinate systems was right handed and anatomically based. The X axis pointed medio-laterally, the Y axis anterior-posterior and the Z axis was vertical and aligned with the long axis of the right side of the body.

To calculate TTB measures, the foot was modeled as a rectangle to allow for separation of the anterior-posterior (AP) and medial-lateral (ML) of CoP (van

Emmerik & van Wegen, 2002). The CoP ML position and velocity was used to calculate TTB ML. If the CoP ML is moving medially, the distance between CoP ML and the medial border of the foot will be calculated. This distance was then divided by the corresponding velocity of CoP ML to calculate the time it would take the CoP ML to reach the medial border of the foot if it were to continue moving in the same direction with no acceleration or deceleration. If the CoP ML is moving laterally, the distance between CoP ML and the lateral border of the foot will be calculated and divided by the corresponding velocity of CoP ML. Thus, a time series of TTB ML measures was generated. A time series of corresponding TTB AP measures was similarly generated by determining the time it would take CoP AP to reach either the anterior or posterior boundary of the foot (Hertel, Olmsted-Kramer, et al., 2006). The absolute minimum and mean of minimum samples in the ML and AP direction represent the temporal margin to the boundary of support and standard deviation of minimum samples in the ML and AP direction represents its variability (Hertel, Olmsted-Kramer, et al., 2006).

The distance scores (cm) for each direction of the SEBT was averaged over the 3 trials and normalized to leg length (reach distance/leg length x 100 = percentage of leg length).

Statistical Analysis

A 3x2 (warm-up x time) Repeated measures Analysis of Variance (ANOVA) was used to identify any alteration in the dependent variables. The independent variables were the three interventions (DS, SS, Control), and time (pre and post).

Three separate ANOVA's was performed on each set of dependent variables: ROM measures (Hip flexion, knee extension, and ankle dorsiflexion), SEBT measures (Anterior, posterior-medial, and posterior-lateral), and TTB measures (the absolute minimum, and standard deviation of minimum in the ML and AP direction). The alpha level for determining significance was set at $\leq .05$ for all calculations and all statistical analyses were performed with SPSS Version 19.0 (SPSS Inc., Chicago, IL).

CHAPTER 4: RESULTS

Fifteen participants completed the entire study. A total of 23 people were screened, 15 were included and 8 were excluded. Nine participants' test leg was the right leg and remaining six was the left leg. Other anthropometrical parameters are provided below (Table 3).

Table 3: Descriptive Statistics

Gender	#	Age	Height(cm)	Weight(kg)	Leg Length(cm)	SIL_KE(°)	SUL_KE(°)
Male	8	24±2.8	179.7±5.1	73.3±10.2	89.9±5.9	36.7±9.9	26.7±8.1
Female	7	26.1±5.6	164.7±4.5	59.1±12.1	79.7±5.3	31.0±8.8	24.1±7.9

SIL_KE=Screen involved limb for knee extension range of motion
SUL_KE=Screen uninvolved limb for knee extension range of motion

Range of Motion

There was a significant main effect (all $p < 0.05$) for time (pre and post). Pairwise comparisons showed that knee extension ROM significantly (F [1, 14] =90.2, P<0.001) increased by 7.5°, hip flexion ROM significantly (F [1, 14] =7.2, p=0.019) increased by 2.2°, ankle dorsiflexion ROM significantly (F [1, 14] =78.2, p<0.001) increased by 0.8cm (Table 4, Table 5, Table 6 and Table 12)

Knee extension ROM significantly (P<0.05) increased regardless of what stretching intervention (SS, DS) or the control (CN) was performed. For the SS, the change in active knee extension ROM between pre and post-test was 7.8°. For the DS, the change in active knee extension ROM between pre and post-test was 6.7°. For the CN, the change in active knee extension ROM between pre and post-test was 7.9° (Table 4).

Table 4: Means and SD of Knee Extension ROM (degree) measures for interventions (SS, DS, and CN)

	Pre Knee Extension	Post Knee Extension	ΔROM	P-value
Static Stretching	32.3 ± 10.2	24.5 ± 11.0*	7.8	P<0.001
Dynamic Stretching	29.7 ± 9.3	23.0 ± 10.2*	6.7	P<0.001
Warm-up only	32.2 ± 9.2	24.3 ± 9.4*	7.9	P<0.001
Overall	31.4 ± 2.3	23.9 ± 2.5*	7.5	P<0.001

*Significant improvement over the pre score

Hip flexion ROM significantly (P<0.05) increased regardless of what stretching intervention (SS, DS) or the control (CN) was performed. For the SS, the change in hip flexion ROM between pre and post-test was 2.7°. For the DS, the change in hip flexion ROM between pre and post-test was 2.2°. For the CN, the change in hip flexion ROM between pre and post-test was 1.8° (Table 5).

Table 5: Means and SD of Hip Flexion ROM (degree) measures for interventions (SS, DS, and CN)

	Pre Hip Flexion	Post Hip Flexion	ΔROM	P-value
Static stretching	130.4 ± 12.4	133.1 ± 12.2*	2.7	P=0.019
Dynamic stretching	128.8 ± 12.8	131.0 ± 10.2*	2.2	P=0.019
Warm-up alone	128.5 ± 12.3	130.3 ± 10.1*	1.8	P=0.019
Overall	129.2 ± 3.1	131.5 ± 2.7*	2.2	P=0.019

*Significant improvement over the pre score

Ankle dorsiflexion ROM significantly (P<0.05) increased regardless of what stretching intervention (SS, DS) or the control (CN) was performed. For the SS, the change in ankle dorsiflexion ROM between pre and post-test was 0.8°. For the DS, the change in ankle dorsiflexion ROM between pre and post-test was 0.7°. For the CN, the change in ankle dorsiflexion ROM between pre and post-test was 0.8° (Table 6).

Table 6: Means and SD of Ankle Dorsiflexion ROM (cm) measures for interventions (SS, DS, and CN)

	Pre Dorsiflexion	Post Dorsiflexion	ΔROM	P-value
Static Stretching	8.1 ± 2.9	8.9 ± 2.9*	0.8	P<0.001
Dynamic Stretching	7.8 ± 2.5	8.5 ± 2.7*	0.7	P<0.001
Warm-up only	8.1 ± 2.6	8.9 ± 2.9*	0.8	P<0.001
Overall	8.0 ± 0.7	8.8 ± 0.7*	0.8	P<0.001

*Significant improvement over the pre score

Dynamic Balance

All three directions for the SEBT (anterior, posteromedial, and posterolateral) significantly (P<0.05) increased regardless of what stretching intervention (SS, DS) or the control (CN) was performed. The anterior (ANT) SEBT direction significantly increased (F [1, 14] =25.3, p<0.001) by 2.71 %, the posterolateral (PM) SEBT direction significantly increased (F [1, 14] =18.9, p=0.001) by 3.10 % and the posteromedial (PL) SEBT direction significantly increased (F [1, 14] =50.9, p<0.001) by 3.93 % (Table 7, Table 8, Table 9 and Table 12).

Both stretching interventions (SS, DS) and the control (CN) significantly (p<0.001) increased in ANT direction of the SEBT. For the SS, the change in ANT direction of the SEBT between pre and post-test was 3.4%. For the DS, the change in ANT direction of the SEBT between pre and post-test was 2.3%. For the CN, the change in ANT direction of the SEBT between pre and post-test was 2.4% (Table 7).

Table 7: Means and SD of normalized anterior (ANT) direction of SEBT for interventions (SS, DS, and CN)

	Pre ANT SEBT	Post ANT SEBT	ΔDistance	P-value
Static Stretching	77.0 ± 6.6	80.4 ± 8.1*	3.4	P<0.001
Dynamic Stretching	75.8 ± 6.7	78.1 ± 8.1*	2.3	P<0.001
Warm-up only	76.7 ± 8.1	79.1 ± 9.0*	2.4	P<0.001
Overall	76.5 ± 1.7	79.2 ± 2.1*	2.7	P<0.001

*Significant improvement over the pre score

Both stretching interventions (SS, DS) and the control (CN) significantly ($p<0.001$) increased in PM direction of SEBT. For the SS, the change in PM direction of SEBT between pre and post-test was 3.7 %. For the DS, the change in PM direction of SEBT between pre and post-test was 3.1 %. For the CN, the change in PM direction of SEBT between pre and post-test was 2.6 % (Table 8).

Table 8: Means and SD of normalized posteromedial (PM) direction of SEBT for interventions (SS, DS, and CN)

	Pre PM SEBT	Post PM SEBT	ΔDistance	P-value
Static Stretching	112.4 ± 7.5	116.1 ± 7.9*	3.7	P=0.001
Dynamic Stretching	111.5 ± 8.1	114.6 ± 8.6*	3.1	P=0.001
Warm-up only	111.6 ± 7.3	114.2 ± 7.9*	2.6	P=0.001
Overall	111.9 ± 1.8	114.9 ± 2.0*	3.1	P=0.001

*Significant improvement over the pre score

Both stretching interventions (SS, DS) and the control (CN) significantly ($p<0.001$) increased in PL direction of the SEBT. For the SS, the change in PL direction of SEBT between pre and post-test was 5.0 %. For the DS, the change in PL direction of SEBT between pre and post-test was 3.6 %. For the CN, the change in PL direction of SEBT between pre and post-test was 3.3 % (Table 9).

Table 9: Means and SD of normalized posterolateral (PL) direction of SEBT for interventions (SS, DS, and CN)

	Pre PL SEBT	Post PL SEBT	ΔDistance	P-value
Static Stretching	104.5 ± 9.3	109.5 ± 10.4*	5.0	P<0.001
Dynamic Stretching	105.3 ± 10.3	108.9 ± 9.9*	3.6	P<0.001
Warm-up only	106.6 ± 9.4	109.9 ± 10.6*	3.3	P<0.001
Overall	105.5 ± 2.4	109.4 ± 2.6*	3.9	P<0.001

*Significant improvement over the pre score

Static Balance

There were no significant differences for the mean of the TTB minima in the ML (F [1, 14] =0.8, p=0.402) and TTB AP (F [1, 14] =0.4, p=0.527) directions (Table 10, Table 11 and Table 12).

Table 10: Means and SD of the TTB minima (s) in the anteroposterior (AP) direction

	Pre AP TTB	Post AP TTB	Δtime	P-value
Static Stretching	2.73± 0.85	2.75 ± 0.87	0.02	P>0.05
Dynamic Stretching	2.69 ± 0.95	2.56 ± 0.74	-0.13	P>0.05
Warm-up only	2.63 ± 1.04	2.86 ± 0.93	0.23	P>0.05
Overall	2.69 ± 0.21	2.73 ± 0.19	0.04	P>0.05

No Significant improvement over the pre score

Table 11: Means and SD of the TTB minima (s) in the mediolateral (ML) direction

	Pre ML TTB	Post ML TTB	Δtime	P-value
Static Stretching	0.98± 0.33	1.03 ± 0.37	0.05	P>0.05
Dynamic Stretching	1.08 ± 0.44	0.96 ± 0.35	-0.12	P>0.05
Warm-up only	0.95 ± 0.33	1.10 ± 0.43	0.15	P>0.05
Overall	1.01 ± 0.08	1.03 ± 0.08	0.02	P>0.05

No Significant improvement over the pre score

Interactions and Stretching Main Effects

Repeated measures ANOVA revealed that there were no significant interaction (all p>0.05) for hip flexion ROM (*F* [2, 28] =0.1, p=0.876), knee extension ROM (*F* [2, 28] =0.4, P=0.675), ankle dorsiflexion ROM (*F* [2, 28] =0.1, p=0.865), all 3 directions for SEBT ANT (*F* [2, 28] =0.9, p=0.427), PM (*F* [2, 28]=0.5, p=0.601), PL (*F* [2, 28] =1.5,p=0.233), TTB ML (*F* [2, 28] =2.3, p=0.114) and TTB AP (*F* [2, 28] =1.1, p=0.349) between interventions (SS, DS, and CN) and time (pretest and posttest) (Table 12).

In addition, there was no significant (all p > 0.05) main effect for stretching interventions (SS, DS) and the control (CN) for any of the dependent variables tested, which involved hip flexion ROM (*F* [2, 28] =2.0, p=0.154), knee extension ROM (*F* [2, 28] =1.8, p=0.177), ankle dorsiflexion ROM (*F* [2, 28] =1.5, p=0.245), all 3 directions for SEBT ANT (*F* [2, 28] =1.2, p=0.323), PM (*F* [2, 28] =0.9, p=0.429), PL (*F* [2, 28] =1.0, p=0.392), TTB ML (*F* [2, 28] =0.03, p=0.969) and TTB AP (*F* [2, 28] =0.3, p=0.764) (Table 12).

Table 12: ANOVA table for intervention, time and interaction main effect

Source	Measure	F value	P value
Intervention	AKET	F [2, 28]=1.846	p=0.177
	HFT	F [2, 28]=2.005	p=0.154
	WBLT	F [2, 28]=1.479	p=0.245
	SEBT_ANT	F [2, 28]=1.178	p=0.323
	SEBT_PM	F [2, 28]=0. 873	p=0.429
	SEBT_PL	F [2, 28]=0.970	p=0. 392
	TTB_ML	F [2, 28]=0.032	p=0.969
	TTB_AP	F [2, 28]=0.271	p=0.764
Time	AKET	F [1, 14]=90.223	P<0.001
	HFT	F [1, 14]=7.238	p=0.019
	WBLT	F [1, 14]=78.193	p<0.001
	SEBT_ANT	F [1, 14]=25.335	p<0.001
	SEBT_PM	F [1, 14]=18.935	p=0.001
	SEBT_PL	F [1, 14]=50.895	p<0.001
	TTB_ML	F [1, 14]=0.754	p=0.402
	TTB_AP	F [1, 14]=0.420	p=0.527
Interaction	AKET	F [2, 28]=0.427	P=0.675
	HFT	F [2, 28]=0.134	p=0.876
	WBLT	F [2, 28]=0.146	p=0.865
	SEBT_ANT	F [2, 28]=0.877	p=0.427
	SEBT_PM	F [2, 28]=0.518	p=0.601
	SEBT_PL	F [2, 28]=1.533	p=0.233
	TTB_ML	F [2, 28]=2.349	p=0.114
	TTB_AP	F [2, 28]=1.092	p=0.349

CHAPTER 5: DISCUSSION

The purpose of this study was to examine the effects of static stretching (SS) versus dynamic stretching (SS) on lower extremity joint range of motion (ROM), static balance, and dynamic balance. The results of this study indicated that both stretching interventions (SS, DS), and the control (CN) resulted in a significant increase on the lower extremity joint ROM (hip flexion, knee extension, and ankle dorsiflexion) and improvement in dynamic balance in all three directions (anterior, posteromedial, posterolateral) of the Star Excursion Balance Test (SEBT). There was no significant difference in static balance, as measured by the Time to boundary (TTB) measure. In addition, there was no significant interaction between interventions (SS, DS, and CN) and time (pre and post) meaning that all changes seen in range of motion and dynamic balance occurred regardless of which intervention (SS, DS, and CN) was performed. This chapter will first discuss our findings and compare them to the previous literature, followed by interpretation and explanation of the findings, limitations, and direction for future research.

Knee Extension Range of Motion

Increased hamstring flexibility is suggested to be an effective way to reduce the incidence of hamstring strains (Liemohn, 1978), which are one of the most common injuries experienced in the sports competition or physical activity (Worrell & Perrin, 1992). In relation to change in ROM of knee extension, our findings showed that all interventions (SS, DS and CN) resulted in a significant knee extension ROM increase. It is interesting to note that 13 out of 15 participants would still have been considered "tight" for our inclusion criteria (knee extension ROM >15°) after each intervention. The less stiff hamstring muscle and more slack connective tissue around the knee joint following stretching (SS and DS), and improved neuromuscular performance (enhanced core body temperature and increased muscular activation) from 5mins jogging warm-up attributed to the increased knee extension ROM.

The observed hamstring flexibility in our results was partly supported by previous research. Bandy et al (1998) found that both SS (pre 41.9 ± 10.1°, post 39.9 ± 6.0°) and DS (pre 30.5 ± 9.1°, post 35.7 ± 6.0°) increased hamstring flexibility (passive knee extension ROM) but SS increased hamstring flexibility significantly more than DS (Bandy et al., 1998). This was consistent with our finding to some extent, which indicated that the change of active knee extension ROM in SS (pre 32.3 ± 10.2°, post 24.5 ± 11.0°) was greater than in DS (pre 29.7 ± 9.3°, post 23.0 ± 10.2°), although no significant difference was found. However, Bandy et al (1998) defined as tight hamstring as having greater than 30° loss of knee extension, which was greater than in our study (>15° met the inclusion criteria). On the other hand, our results added to the inconclusive findings from previous research. O'Sullivan et al (2009) revealed that knee extension ROM significantly increased with 5 minutes warm-up, then further increased with SS but significantly decreased after DS in those with previous injured hamstring (O'Sullivan et al., 2009). This partly contradicted with our results that DS significantly increased knee extension ROM rather than a decrease, and the increase of SS and warm-up alone was almost identical. Moreover, De Weijer et al (2003) found that warm-up alone only (10 minutes of stair climbing at 70% of maximum heart rate) minimally increase knee extension ROM while the greatest increase (10.3°) appeared in the warm-up and SS (30s passive static stretches of the hamstring) group (De Weijer, Gorniak, & Shamus, 2003). Our study found a similar increase in knee extension ROM following warm-up alone (CN), however, we did not find any additional increase in knee extension ROM (SS 7.9° vs CN 7.8°) following SS.

There were some methodological differences between the studies, which may explain the differences within the results. To begin with, the current study and De Weijer et al (2003) measured subjects' knee extension ROM by active knee extension test (AKET), whereas O'Sullivan et al (2009) and Bandy et al (1998) used passive knee extension test (PKET). It has been demonstrated that values obtained for knee extension ROM using PKET and AKET varied by almost 12°, since AKET may only measure initial hamstrings length whereas PKET measured maximal hamstrings length (RL Gajdosik, Rieck, Sullivan, & Wightman, 1993). This might have resulted in the different outcomes. Secondly, the target muscle of stretching was different within studies. The hamstring was the only main muscle stretched in Bandy et al (1998), O'Sullivan et al (2009) and De Weijer et al (2003), whereas our study focused on three main muscle groups: quadriceps, hamstrings, and plantar flexors. Thus, our stretching protocol might be more effective on the subsequent knee extension ROM performance after stretching. Thirdly, in order to maximally increase ROM in tight hamstrings, the duration of SS plays an important role in the subsequent effects. Bandy & Irion (1994) demonstrated that 30s and 60s of SS were more effective at increasing flexibility of hamstring muscles than stretching for 15s, and 30s of SS was as effective as the longer duration of 1 minute on the improvement of hamstring tightness (Handrakis Bandy & Irion, 1994). The duration of SS in our study was 30s, which was consistent with Behm et al (2011). However, Bandy et al (1998) examined the effects of hamstring flexibility before and after 6 weeks stretching interventions, while the current study and other previous research focused on the acute effect of stretching conditions.

Ankle Dorsiflexion Range of Motion

It has been demonstrated that calf muscle stretching was an effective method to increase ankle dorsiflexion, which could reduce the symptoms of disorders with associated with calf muscle tightness (Radford, Burns, Buchbinder, Landorf, & Cook, 2006). Our results showed that all interventions (SS, DS and CN) resulted in a significant ankle dorsiflexion ROM increase. The increased ankle dorsiflexion ROM might have been mainly due to the improved calf muscle flexibility resulting from the stretching interventions (SS, DS) and advantage of faster nerve conduction velocity following warm-up (jogging). This resulted in more compliant calf muscle and less ankle joint stiffness. In addition, Samukawa et al (2011) found that a significant distal displacement of the myotendinous junction was observed by ultrasonography after DS. Thus, the lengthen ankle plantar flexor muscle–tendon following DS might be another contributor to increased ankle dorsiflexion (Samukawa, Hattori, Sugama, & Takeda, 2011). Therefore, both factors might be responsible for generating more distance between the great toe and the wall as measured maximal ankle dorsiflexion ROM in the Weight-bearing Lunge Test.

We chose to use the Weight-bearing Lunge Test (WBLT) to assess dorsiflexion ROM because it has been thought to more accurately reflect the available ankle dorsiflexion ROM and more reliable than in a non-weight-bearing position (Bennell et al., 1998). Most measurement techniques for weight-bearing ankle dorsiflexion ROM include the use of a standard goniometer (Norkin, 2009), an inclinometer (Cosby & Hertel, 2011), or a tape measure (Matthew C Hoch & McKeon, 2011). A tape WBLT measure that was used in our study has been proven to not require the technical proficiency associated with a goniometer or inclinometer and is more sensitive to change compared to measures of motion in degrees (Collins, Teys, & Vicenzino, 2004). Therefore comparison of our data to previous studies should be interpreted with caution.

Previous research found that the combined stretching protocol (running first, then SS) (pre 18.3 ± 6.2°, post 20.6 ± 5.6°) was more effective than the running only (pre 18.6 ± 6.6°, post 18.8 ± 6.1°) for increasing ankle dorsiflexion ROM (McNair & Stanley, 1996), while our study did not find any significant difference within SS intervention (pre 8.1 ± 2.9 cm, post 8.9 ± 2.9 cm) and the control (warm-up alone) (pre 8.1 ± 2.6 cm, post 8.9 ± 2.9 cm). The Weight-bearing Lunge test was measured as electrogoniometer in McNair & Stanley (1996) study, while our study used a tape measure. In addition, the current study designed a warm-up alone protocol with self-control comfortable speed jogging on treadmill, which was different with controlling at 60% maximum heart rate running in McNair & Stanley (1996). This could result in different aerobic metabolism performance. Moreover, Hoch et al (2011) found that the mean value of the WBLT was 11.9 ± 2.7 cm in healthy population, which was relatively greater than our finding (SS pre 8.1 ± 2.9 cm, DS pre 7.8 ± 2.5 cm, CN pre 8.1 ± 2.6 cm) (M.C. Hoch et al., 2011). The inclusion criteria of having tight calf muscle may explain this difference. Youdas and associates indicated that a 30s or 60s per day for 6-weeks SS did not significantly increase active ankle dorsiflexion ROM in healthy subjects (Youdas, Krause, Egan, Therneau, & Laskowski, 2003). Our study focused on acute effect of SS on ankle dorsiflexion ROM in those who have tightness in their hamstring and calf muscles, while Youdas et al (2003) examined a relative longer (6-week) stretching intervention in healthy population without specific reference to muscle tightness. The effect of SS on a healthy population ankle dorsiflexion ROM might be not as distinct as in those with tight muscles.

Hip Flexion Range of Motion

With regard to alternations in ROM of hip flexion, our results showed that all stretching interventions (SS, DS and CN) resulted in a significant hip flexion ROM increase. The improved hip ROM was mainly due to the increased hamstring flexibility following stretching interventions (SS and DS). In addition, enhanced body temperature after warm-up might also result in a beneficial effect.

The pre value of hip flexion ROM in our finding (SS 130.4 ± 12.4°, DS 130.4 ± 12.4°, CN 128.5 ± 12.3°) was all greater than in Pua et al (2008) (118.8±15.9°) (Pua et al., 2008). However, Pua et al (2008) focused on those with hip osteoarthritis that might have greater limitation of hip flexion ROM than the young healthy subjects in our study.

Our results were consistent with Godges et al (1989), who compared the two stretching techniques (Static stretching and Proprioceptive neuromuscular facilitation) to determine which was most effective for improving hip ROM. SS resulted in significant improvement in hip flexion ROM (Godges, MacRae, Longdon, Tinberg, & Macrae, 1989), which was similar to our study. Our finding was also supported by Cipriani et al (2003)'s research, which demonstrated significant gains in ROM for hip flexion over the 6 weeks training (2 minutes stretching twice daily), although they only stretched hamstring muscles (Cipriani, Abel, & Pirrwitz, 2003).

However, there were no significant changes in flexibility as a result of either warm-up in Young et al (2004), whose protocol involved five minutes of sub-maximum running followed by seven practice kicks and following 4.5 minutes SS of the hip flexors and quadriceps. This could be resulted from different warm-up protocol design. Young et al (2004) added practice kicks while our protocol did not involve them. In addition, hip ROM in Young et al (2004) was measured in hip extension using a modified Thomas test, which may not have been sensitive to estimate the acute change in flexibility from warm-up and stretching (W Young, Clothier, Otago, Bruce, & Liddell, 2004).

Dynamic Balance (SEBT)

With respect to improvement in dynamic balance, our results showed that all interventions (SS, DS and CN) resulted in a significant increase in three directions

(ANT, PM, and PL) of SEBT, which indicated that dynamic balance performance was improved despite no difference occurred within interventions. The possible reason behind this might be due to a desensitized stretch reflex after an increased muscle and joint flexibility following stretching. As a result, a less responsive stretch reflex could suppress the postural deviations, thus make it easier to establish dynamic equilibrium (A. G. Nelson et al., 2011).

For the ANT direction of the SEBT, the pre value of our results (SS pre 77.0 ± 6.6 %, DS pre 75.8 ± 6.7%, and CN pre 76.7 ± 8.1%) was slightly smaller than Hertel et al (2006) finding in healthy subjects (79 ± 12 %). However, the pre value of the PM (SS pre 112.4 ± 7.5%, DS pre 111.5 ± 8.1%, CN pre 111.6 ± 7.3%) and PL (SS pre104.5 ± 9.3%, DS pre 105.3 ± 10.3%, CN pre 106.6 ± 9.4%) directions of the SEBT was both greater than Hertel et al (2006) finding (PM 90 ± 13%, PL 81 ± 13%) (Hertel, Braham, et al., 2006). This comparison is interpreted as despite the participants in our study having tight calf and hamstring muscles, their dynamic balance performance was similar to previously reported healthy subjects.

To better understand the relationship between increased joint ROM and increased SEBT performance seen in our study, we conducted a post-hoc correlational analysis of these variables. None of the pre-test ROM measurements were significantly correlated with the SEBT reach distance in any direction (Appendix G). Previously, Hoch et al (2011) examined the relationships between dorsiflexion range of motion on the WBLT and normalized reach distance in three directions on the SEBT in healthy subjects (M.C. Hoch et al., 2011). They found that the ANT direction of the SEBT (mean: 79.0 ± 5.8%) was significantly correlated to the WBLT (mean: 11.9 ± 2.7 cm; $r = 0.53$, $r^2= 0.28$, $p = 0.001$) and dorsiflexion ROM accounted for an estimated 28% of the variance in ANT reach, while there were no significant correlations between the WBLT and the PM direction (mean: 90.0 ± 9.1%; $r = 0.21$, $r^2 = 0.04$, $p = 0.23$) or the PL direction (mean: 82.0 ± 13.1%; $r = 0.22$, $r^2= 0.05$, $p = 0.20$). However, our results did not find any significant correlation between the dorsiflexion ROM and 3 normalized reach distances, which was consistent with previous research (P. A. Gribble & Hertel, 2003). One thing need to be noted that the subjects in our study were those with tight calf and hamstring muscles, and these participants may differ from “typical healthy” participants in terms of mechanical properties of the muscle, muscle-tendon, and connective tissue in the lower extremity. Therefore, the tight muscle might limit the relationship between dorsiflexion ROM and the SEBT performance in our study. A new contribution to the literature on SEBT performance is that it does not appear to be related to available joint ROM in hip flexion, knee extension, or dorsiflexion.

A second set of post-hoc correlations was performed to determine if there was a relationship between the amount of ROM gained following the intervention (ΔPre-Post ROM) and the improvement in SEBT score (ΔPre-Post reach distance). Results of this analysis indicated that the gained hip flexion ROM was significantly correlated with the improvement PM direction of the SEBT for the DS intervention ($r = 0.57$, $r^2= 0.32$, $p = 0.03$) (Appendix G). This is not surprise since previous research has shown that hip flexion alone accounted for 88.6% and 94.5% of the variance in the PM and PL directions, respectively (Robinson & Gribble, 2008). The additional hip flexion ROM may contribute to the improved SEBT by allowing lower center of mass to produce greater potential leg reach distance. No significance was found for the remaining correlation between the increased ROM and the improved SEBT.

Previous research examined the effects of SS on dynamic balance using different dynamic balance measurements, Biodex Medical System (BBS) (Pablo B Costa, Barbara S Graves, Michael Whitehurst, & Patrick L Jacobs, 2009) , Dynamic Stability Index (DSI) , and stabilometer (A. G. Nelson et al., 2011), but none have used the SEBT. Therefore, comparison of our finding to previous research should be illustrated with caution.

Our findings agreed with Costa et al (2009) research, who evaluated the effects of different durations (15s and 45s) of SS on dynamic balance on young women. The SS protocols was based on Behm et al (2004) but involved with 15s and 45s duration. Dynamic balance was measured as using the Biodex Medical System, which was similar to actual physical activities that resulted in postural instability. A warm-up on a cycle ergometer at 70 rpm for 5 minutes was performed before each condition. The results of this study indicated that SS of 45s did not adversely affect dynamic balance and 15s of SS improved dynamic balance. This suggested that shorter duration of SS (15s) might be more effective on dynamic balance improvement, however, our SS protocol resulted in improvement in the 3 directions of the SEBT utilizing a 30s duration SS protocol. Future study need to further compare with the different duration of SS under various dynamic balance measurements. In addition, they did not find any significant change in the control condition (warm-up alone), although they used a similar cycle warm-up protocol as Behm et al (2004).

Dynamic Stability Index (DSI) was another dynamic balance measurement that has been used to test dynamic postural control using a single-leg stance. Smaller DSI meant improved dynamic balance while greater DSI indicated opposite effect (Handrakis et al., 2010). Handrakis et al (2010) found that DSI of SS group (no aerobic warm-up, SS alone) was significantly smaller than that in the NS group (no aerobic warm-up). However, their recruited subjects were from martial arts school, which was quite different from healthy recreationally active individuals who have not experienced specific martial or exercise training in the current study.

In comparison with non-balance trained individuals with experienced balance trainers, Nelson et al (2011) found that balance time for non-balance trained individuals improved significantly by 11.4% (2s increase), but no significant change in the experienced balance trainers (surfers). Balance testing was performed on a stabilometer following either 30 min of quiet sitting or 30 min of SS protocols (20 mins stretching and 10 mins relax, no aerobic warm-up for both groups) (A. G. Nelson et al., 2011).

All previous studies focused on the effect of SS on dynamic balance, none of them focused on the effect of DS on dynamic balance. Our study, therefore, added preliminary data to understand the effects of DS on dynamic balance (SEBT) performance, and based on these data neither stretching condition had a significant effect on dynamic balance.

Static Balance (TTB)

In relation to modification in static balance, our results showed that none of the interventions (SS, DS and CN) had a significant effect on the mean of TTB minima in the anterior-posterior (AP) and in the medio-lateral (ML) directions. This meant that all three interventions (SS, DS, and CN) had no effect on static balance. The pre values of the mean of TTB AP (SS 2.73 ± 0.85, DS 2.69 ± 0.95, CN 2.63 ± 1.04) and TTB ML minima (SS 0.98 ± 0.33, DS 1.08 ± 0.44, CN 0.95 ± 0.33) in our study were all relatively smaller than from Mckeon et al (2008) finding (TTB AP 5.32 ± 1.77 and ML 1.84 ± 0.53) in those with a history of chronic ankle instability (CAI) (Mckeon et al., 2008). The mean of the TTB minima for the ML and the AP directions represents the measurement of TTB magnitude, which indicates the times where the sensorimotor system had the least time to make a postural correction to maintain single leg stance over the base of support (Hertel, Olmsted-Kramer, et al., 2006). Thus, our results indicated that the subjects with tight calf and hamstring muscle was more prone to postural instability than those with CAI. One point should be note that the DS intervention resulted in a tendency to decrease TTB AP (pre 2.69 ± 0.95s vs post 2.56 ± 0.74s) and TTB ML (pre 1.08 ± 0.44s vs post 0.96 ± 0.35s), while SS and CN increased in TTB AP (SS pre 2.73± 0.85s vs post 2.75 ± 0.87s; CN pre 2.63 ± 1.04s vs 2.86 ± 0.93s) and TTB ML (SS pre 0.98 ± 0.33s vs post 1.03 ± 0.37s; CN pre 0.95 ± 0.33s vs post 1.10 ± 0.43s), although there was no significant difference. Since we hypothesized a lower TTB measure indicated greater postural instability (Hertel, Olmsted-Kramer, et al., 2006), DS might negatively affect static balance.

The first possible explanation of observed finding on static balance might be that the current DS protocol (5 min warm-up plus 4 repetitions with 30s of bilateral DS of the quadriceps, hamstrings, and plantar flexors) might cause fatigue for subjects, which resulted in a relatively lower TTB value since fatigue has been previously proven to adversely affect balance (Vuillerme, Burdet, Isableu, & Demetz, 2006). This is because the slow rate of firing of muscle spindles and reflex receptors caused by fatigue could result in the slow nerve transmission rate from CNS to maintain the center of gravity within their base of support, thus static balance. Therefore, the positive effect of DS on static balance that we hypothesized might be compensated by fatigue factor. In addition, since sensory systems (vision and vestibular) was thought to maintain static postural control (L. M. Nashner, 1981), the fact that no significant difference was found in static balance might be due to the role of sensory systems in regulating the static postural control greater than improved neuromuscular performance resulted from stretching interventions (SS, DS) or a general warm-up.

Our finding was supported by Lewis et al (2009), who utilized a comprehensive balance measurement, consisting of Postural Evoked Response Test, Adaptation Test, Motor Control Test, Sensory Organization Test, and Unilateral Stance Test to assess the effect of SS on postural control without any aerobic warm-up component. No significant effect of lower extremity stretching on postural control was detected (Lewis et al., 2009). Conversely, after evaluating the effect of an acute SS on balance, force, proprioception, reaction time and movement time, Behm et al (2004) found that an acute SS adversely affected static balance performance (decreasing for 9.2%) and reaction/movement time (increasing for 4.0% and 1.9%), while the control condition (warm-up alone) increased the balance score for 17.3% and decreased reaction/movement time for 5.8% and 5.7% (Behm et al., 2004). Both conditions involved a 5-min cycle on a cycle ergometer at 70 rpm with 1-kp resistance warm-up. Thus, the obtained positive effect might be due to the enhanced body temperature physiological benefits after cycle warm-up. The static balance was measured as a computerized 30s wobble board test. Since the wobble board involved unanticipated perturbations to equilibrium and was multidirectional that could be a more complex task, it might be more difficulty to maintain static postural control compared with TTB that participants stood on a stable platform in our study. In addition, Nagano and his associate also indicated that stretching of the calf muscles has the effect on increasing postural sway (Nagano et al., 2006). Future research need to determine if stretching could alter sensory systems, which is vital important in those sports that static postural control plays in a critical role.

The control group of our study showed no significant improvement in static balance with SS. The reason might be that the negative effects of SS on static balance that we hypothesized was diluted by a positive effect of a jogging component of the warm-up (Warren Young & Elliott, 2001). The jogging that the current study involved is a common warm-up section. Based on Behm et al (2004), it could be speculated that in the absence of the 5 min of jogging warm-up, the static balance performance might have been decreased to a greater extent. Therefore, future studies should consider avoiding active warm-up influence when designing a stretching protocol.

Mechanisms Relating Stretching to Range of Motion and Balance

The results of this study indicated that all interventions (SS, DS, and CN) resulted in a significant increase on the lower extremity joint ROM (hip flexion, knee extension, and ankle dorsiflexion) and improvement in dynamic balance. Although the mechanisms responsible for the increases in balance performance following stretching have not been thoroughly investigated, several mechanisms based on previous research will be discussed with the current findings.

One explanation for our findings of both increased ROM and improved dynamic balance is that all three of the interventions included a general aerobic warm-up. The observed benefits of improved neuromuscular performance might also be due to elevated muscle and body temperature (Fletcher & Jones, 2004). The similarity of warm-up and DS is the aerobic nature of the task, which could allow for an increase in body temperature. This would positively affect the force-velocity and length-tension relationships, enhance nerve receptor sensitivity, and nerve conduction velocity (Morrin & Redding, 2013; Worrell, Smith, & Winegardner, 1994). One explanation for our findings of both increased ROM and improved dynamic balance is that all three of the interventions included a general aerobic warm-up. Although body temperature was not measured, it is possible that even a small change in temperature led to the positive effects that have been previously described in the literature.

Our results contradicted the previous mechanism that stiffer muscle producing a greater reflex response resulted in greater or more rapid responses to slight perturbations in muscle length, thus better dynamic balance performance (Petit et al., 1990), since our data reached the opposite direction that less stiff muscle resulted from stretching (SS or DS) or jogging warm-up might contribute to the beneficial effect on dynamic balance. In addition, the current data also questioned Behm et al (2004)'s view with related to the alteration in musculotendinous (MTU) influence on static balance. The increase ROM is commonly due to increase the length and decrease stiffness of MTU, which incorporates the muscle, tendon, and other associated connective tissue (G. J. Wilson et al., 1994), following stretching (G. Wilson et al., 1992). A more compliant MTU might decrease the rate of force transmission and the rate at which changes in muscle length or tension detected by the Golgi tendon organs (GTO) (Bishop, 2003a). As a result, it might decrease the ability of stretch receptors to provide proprioceptive input, thus negatively affecting static balance, reaction and movement times (Behm et al., 2004). However, our results did not find any change on static balance (TTB) after stretching (SS and DS). Therefore, our data do not explicitly support either one of these proposed relationship between stretching and balance.

Our finding that both stretching interventions (SS and DS) and the control resulted in increased dynamic balance performance agreed with Nelson et al (2011)'s theory as mentioned before, which suggested that the enhanced ability to maintain dynamic balance after an increased flexibility resulted from stretching was due to a desensitized stretch reflex (Nelson et al., 2011). As a result, a less responsive stretch reflex could suppress the postural deviations, enhance the proprioceptive input, and thus make it easier to establish dynamic equilibrium. This view was further supported by Ghaffarinejad et al (2007), who suggested that knee joint position sense improved following SS due to increased proprioceptive sense (Ghaffarinejad et al., 2007).

Our data demonstrate that regardless of the mode of stretching performed ROM and dynamic balance improved. We did not directly measure MTU stiffness, so these comparisons are made with caution. Additional research is needed to more clearly understand the relationship between altered ROM, MTU stiffness, and balance.

Limitations and Directions for Future Research

One of the limitations of this study was the possibility of a learning effect, particular for the SEBT measurements. We used a standard protocol that has been established to minimize the potential for a learning effect (Hertel, Braham, et al., 2006). Other strategies to control this were the questionnaire, orientation session and practice trials. Despite these efforts it is possible that participants improved their SEBT scores from practice alone. The fact that all stretching interventions improved the SEBT scores similarly could indicate that a learning effect was present.

Previous study indicated that the combined stretching protocol consisting of SS and DS displayed significantly greater changes in hamstring muscle ROM than DS and further showed lower COP movement compared to SS and NS (Morrin & Redding, 2013). However, the current study did not examine the effects of combined stretching (SS and DS) on ROM and balance. Therefore, the finding of this study was limited to compare with the effect of the combined stretching protocol.

Our results are also limited to the acute effects of stretching, no conclusion was made in terms of the long-term effect. Further research need to compare the difference between acute and long-term effect with SS and DS.

Although several mechanisms have been proposed to illustrate the relationship of stretching on ROM and balance, additional research is needed to further examine the exact mechanism to thoroughly explain the alternations in ROM and balance performance after stretching interventions (DS and SS).

The control group of our study showed a significant improvement in ROM and SEBT performance and there was no additional improvement with SS or DS. The reason might be that the effects of SS was diluted by a positive effect of a jogging warm-up (Warren Young & Elliott, 2001). Therefore, future studies should consider avoiding active warm-up influence.

The subjects in the current study were those who are recreationally active individuals with hamstring and calf muscle tightness, future research need to investigate if the finding of this study would apply to general population, athletes, or patients with specific disorder.

Our study used a practical combination of lower extremity stretches, which was considered to be a common stretching routine performed before exercising or participating in an athletic event. The duration and number of repetitions were consistent with Behm et al (2011). Future research need to comprehensively compare the effects of different designed stretching protocols.

Conclusion

The results of this study indicated that all interventions (SS, DS, and control (CN)) resulted in a significant increase on the lower extremity joint ROM (hip flexion, knee extension, and ankle dorsiflexion) and improvement in dynamic balance, meaning that all alterations observed ROM and dynamic balance occurred regardless of which stretching intervention was conducted.

Although recent studies have demonstrated that SS reduced force, strength and power production, the results of our study did not find any negative effect with regard to SS. In addition, our finding added preliminary data to begin to understand any potential effects of DS on dynamic balance performance.

The clinical significance of this study will add the body knowledge that will allow coaches, athletic trainers, and fitness professionals to make evidence based decisions on how to prepare the individuals for utilizing a proper stretching technique during warm-up session, especially in those sports that static or dynamic postural control plays in a critical role. Based on our data, it appears that a general warm-up period followed by either SS or DS will have a positive effect on joint ROM and dynamic balance. The findings of the current study also may inform future research that focus on lower extremity functional balance rehabilitation with specific stretching technique, particularly for those who with tight hamstring or calf muscle patients. The scientific impact of this study is that future studies should attempt to consider the mechanisms behind each intervention separately (i.e. MTU stiffness, body temperature, proprioception, etc.) in order to more specifically understand the relationship between stretching, balance, and joint ROM. In addition, future studies should consider avoiding active warm-up influence when designed a stretching protocol.

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Appendix A

IRB Manager Protocol

SECTION A: Title

A1. Full Study Title: The Effects of Static Stretching versus Dynamic Stretching on Lower Extremity Joint Range of Motion, Static Balance, and Dynamic Balance

SECTION B: Study Duration

B1. What is the expected start date?

03/15/2013

B2. What is the expected end date?

12/31/2014

SECTION C: Summary

C1. Write a brief descriptive summary of this study in Layman Terms (non-technical language):

The area of the research is in biomechanics in the field of Kinesiology. This study will investigate the effects of two stretching techniques on joint range of motion and balance performance. Healthy individuals who demonstrate muscular tightness in the hamstring and calf muscle will be recruited to participate. All participants will have their hip, knee, and ankle range of motion, and balance measured before and after they complete two different stretching protocols. The first stretching protocol uses static stretches (holding the muscle in a stretched position for about 30 seconds) and will stretch the hamstring, quadriceps, and calf muscles. The second stretching protocol uses dynamic stretches (the participant actively moves the leg through functional movements to stretch the muscle) and focuses on the same muscle groups as above. The range of motion and balance tests will be done before and after the stretching, on two different days.

C2. Describe the purpose/objective and the significance of the research:

The purpose of this study is to examine the effects of two stretching techniques on range of motion in the ankle, knee and hip, and balance performance. This study may help establishing favorable stretching technique on how to prepare the individuals with hamstrings and calf muscle tightness during warm-up session. Also, the findings of this study could be used to design better rehabilitation protocol on functional balance.

C3. Cite any relevant literature pertaining to the proposed research:

Static stretching (SS) and dynamic stretching (DS) are often utilized for a wide variety of populations to be an essential part of a warm-up. The benefits of stretching include, but are not limited to, improved joint range of motion (ROM), enhanced muscular performance, and reduced risk of injury. However, there was recently doubt over the effectiveness of SS. Studies have demonstrated that SS decreased an individual's performance in force, strength, and power. These performances included maximal voluntary contraction (MVC) isometric force, one repetition maximum lifts, vertical jump, sprint, running, and agility effects. It is therefore increasingly suggested that individuals should turn to DS warm-up to more closely mimic movements in the subsequent training exercise or sports competition. DS has been shown to improve muscular performance including shuttle run time, medicine ball throw distance, jump and sprint performance, and leg extension power.

Postural stability, or balance, relies heavily on the contribution of information from proprioceptive receptors located within the muscle and connective tissue. Because stretching changes the length of the muscles and tendons, it is possible that either DS or SS may have an influence on proprioception, and therefore balance. There has been little research focusing on the relationship between stretching and balance. Balance can be further divided into static balance (maintaining stability in a single leg stance position) or dynamic balance (maintaining stability during movement). Several studies support that SS enhanced or had no adverse effect on dynamic balance. Costa et al evaluated the effects of different durations of SS on dynamic balance. The results of this study indicated that SS of 45s did not adversely affect dynamic balance while SS with 15s may improve dynamic balance. Handrakis et al found that ten minutes of acute SS enhanced dynamic balance in active middle-aged adults. Furthermore, Nelson et al found that SS improved maintenance of balance for non-balance trained individuals, but not for the experienced balance trainers. For static balance, Behm et al found that there was a significant ($P < 0.009$) decrease in balance scores in the SS condition (decreasing for 9.2%) compared with the control condition (increasing for 17.3%). This was consistent with Nagano et al's finding, which suggested that SS of the calf muscles increased postural sway, and thus adversely affected static balance. It is still unclear what effects DS has on static or dynamic balance, since no research has been conducted in this area. Since individuals with hamstring and calf muscle tightness are likely to have a more robust response to stretching it is necessary to examine how stretching and balance are related in this population.

SECTION D: Subject Population

D1. Identify any population(s) that you will be specifically targeting for the study

None

Describe the subject group and enter the total number to be enrolled for each group.

15 healthy adults with muscular tightness in the calf and hamstring muscles will be enrolled in this study.

D3. List any major inclusion and exclusion criteria

<u>Inclusion Criteria</u>

1) Male or female

2) Age 18-45 years

3) Recreationally active (engage in some form of physical activity at least 30mins and 3-4 days per week)

4) Tightness in the hamstring muscles (assessed via the Active Knee Extension Test, described later)

5) Tightness in the calf muscles (assessed via a deep squat test, described later) Healthy, active males and females are being recruited for this study. To maximize the potential effects

of the stretching protocols individuals with tightness in their hamstrings and calf are forming the sample.

Exclusion Criteria

1) Lower extremity pain or injury in the past 6 months
2) Any other physical deficit that will limit them to perform the balance testing and stretching protocols
3) History of concussion or balance disorders within the last 6 months
4) History of participating in a proprioceptive or balance training in the past 6 months

Factors such as pain, injury, or other conditions that impair balance or stretching are being excluded as they may potentially influence the measurements. To create a more homogenous sample, individuals with specific balance or proprioceptive training are also being excluded.

SECTION E: Informed Consent

E1. Describe how the subjects will be recruited

Participants will be recruited by informational flyers (Appendix A) posted at University of Wisconsin-Milwaukee. The flyers will provide the contact information of the investigator and a brief description of the study including the purpose, and the criteria for inclusion and exclusion. The primary investigator will also request permission from course instructors to make announcements prior to classes (i.e. KIN 270, 320, 460) offered in the Department of Kinesiology.

E2. Describe the forms that will be used for each subject group

Standard adult informed consent will be used for each subject.
Recruitment flyer- to be posted on the UWM campus
Screening Questionnaire- to determine study eligibility
Data collection form- to record the measurements

E3. Describe who will obtain consent and where and when consent will be obtained

The Co-PI (Wang) will obtain the consent during orientation session at Neuromechanics Laboratory (Enderis Hall, Room 132A) at University of Wisconsin-Milwaukee. All participants will have the opportunity to ask questions in person prior to giving their written consent to participate. The consent process will continue informally throughout the study and participants will be reassured that they are free to withdraw penalty or harm.

SECTION F: Data Collection and Design

F1. In the table below, chronologically describe all study activities where human subjects are involved.

A. Activity Name:	B. Activity Description:	C. Activity Risks and Safeguards:
Recruiting	Participants will be recruited by informational flyers (Appendix A) posted at University of Wisconsin-Milwaukee. The flyers will provide the contact information of the investigator and a brief description of the study including the purpose, and the criteria for inclusion and exclusion. The primary investigator will also request permission from course instructors to make announcements prior to classes (i.e. KIN 270, 320, 460) offered in the Department of Kinesiology. Recruitment will begin in March 2013 after IRB approval is received, and continue until May 2013	No risk
Consent	All study activities will occur in the Neuromechanics Laboratory (Enderis 132). All participants will be informed of the study equipment and procedures and will provide written consent in accordance with institutional guidelines. The consenting process should take no longer than 10 minutes	No risk
Testing sessions	There will be 4 testing days each occurring between 48-96 hours apart. Day 1- Screening and practice of balance tests and stretching protocols (60 minutes) Day 2,3,4 (60 minutes) o Range of motion tests o Balance assessment o Stretching protocols (each performed on a different day: Dynamic Stretch, Static Stretch, Warm-up only(control)) o Balance assessment o Range of motion tests	Minimal risk- participants will be given instructions and allowed to practice each test until they feel comfortable.
Screening	• All screening and data collection will occur in the Neuromechanics Laboratory (Enderis 132) • Only the dominant leg (defined as the leg with which the participant would kick a ball) will be screened and tested. • The Screening Questionnaire (Appendix B) will be completed. • Two screening tests (active knee extension (AKE) test and deep squat (DS) test) will be provided for participants to meet the inclusion criteria: <u>AKE Test</u> Participants will be in supine position with the non-test leg in a straight resting position on an examination table. A small bench will be placed under the test leg with the hip and knee flexed to 90º. A strap will be placed around the non-test leg and the table	Minimal risk- participants will be given instructions and allowed to practice each test until they feel comfortable.

	at the mid-thigh position to prevent movement of this leg during testing. A second strap will be placed around the test leg thigh and bench to maintain the hip in a vertical position. A fluid inclinometer will be placed on the lateral mid-shin and lateral mid-thigh of the test leg and used to measure the knee extension angle. Participants will be instructed to actively straighten their test leg as far as possible. The inclinometer will measure the angle between the shin and vertical. The measured angle greater than 15° from the vertical position will meet the inclusion criterion of hamstring tightness. <u>Deep Squat Test (DS)</u> Participants will be standing and be asked to hold a light wooden dowel and press it over their head with the feet shoulder width apart. Participants will be instructed to squat down as low as they can while keeping their heels on the floor, keeping the dowel above their head. Participants who can successfully squat down so that their thighs fall past horizontal while keeping their heels on the floor DO NOT have calf tightness, and will therefore be excluded. Participants who cannot complete the deep squat as described DO have calf tightness and will be included in the study. • Height and weight will be measured using a standard scale and stadiometer. • Leg length will be measured from the Anterior Superior Iliac Spine to the most distal point of the medial malleolus. The screening tasks should take no longer than 10 minutes	Participants will be assigned a unique code that will not be identifiable. The only document that links participant's information with the code will be kept by the primary investigator in a locked cabinet. This document will be destroyed upon completion of the study.
Task practice	Height, weight, and leg length will be measured and recorded on the Data Collection Form (Appendix C). During the screening session (Day 1) participants will be instructed on each of the balance assessments and stretching protocols as described below. All participants will be required to practice each test/stretch 3-5 times to minimize the learning effect and ensure proper performance of each task. The task practice session should take no longer than 60 minutes.	Minimal risk- participants will be given instructions and allowed to practice each test until they feel comfortable.
Range of motion tests	• Laboratory sandal and tight-fitting shorts will be provided to participants for the testing session. The range of motion test should take no longer than 15 minutes • Range of motion tests will be performed before and after each balance assessments. o <u>Hip Flexion</u>: participants will be in the supine position. A fluid inclinometer will be attached to a strap around the thigh of the test leg, and zeroed with the leg in a horizontal resting position. The	Minimal risk- participants will be given instructions and allowed to practice each test until they feel comfortable.

	investigator will then flex the hip with the knee in flexion, until a firm end feel is reached. Hip flexion angle will be then measured by the fluid inclinometer relative to the horizontal plane. o <u>Ankle Dorsiflexion:</u> participants will be in standing position facing a wall approximately 3 inches away from the wall. The opposite leg will be used to maintain stability behind the test leg. Keeping the second toe, center of the heel and knee in line, and keeping the test heel firmly planted on the floor, participants will lunge forward to touch the wall with their knee. If successful, the stance foot will then be incrementally moved away from the wall until the knee can no longer touch the wall while keeping the heel on the ground. This will be defined as maximal dorsiflexion, and measured as the distance between the great toe and the wall. The investigator will use a tape-measure the furthest distance. o <u>Knee Extension:</u> The AKE test, as described in the screening section, will be used to assess the knee extension ROM. This test will not be repeated, as the measurement was made during the screening.	
Balance assessments	• Static Balance Test (Time-to-boundary): Participants will place the dominant leg on the center of the force plate. The hands will be kept on the waist, while the opposite leg will be flexed at the hip and knee to approximately 30°. After the participant feels stable in their single leg stance, they will be asked to close their eyes, and data collection will begin. A computer and software program will be used to record the movement of the Ground Reaction Force, which will be used for data analysis. Participants will perform three, 10s trails. • Dynamic Balance Test (Star Excursion Balance test): Participants will stand in the center of a "Y" shaped grid marked on the floor. The great toe will be placed at a mark in the center of the grid. Standing on the test leg, participants will be instructed to maintain a single-leg stance while the contralateral leg reaches as far as possible along each of the 3 lines extended from the center of the "Y" (anterior, posteromedial, and posterolateral) and touches the line as lightly as possible with distal part of their reach foot then will return to a bilateral stance. The reach distance will be marked with a pencil on the floor immediately after each trail. Participants will complete 3	Minimal risk- minor muscle soreness similar to mild physical activity

	trials in each direction with 30s rest between each trial. The investigator will manually measure the distance in centimeters from the center of the grid to each touch point with a tape measure, and use these data for analysis. The balance assessments should take no longer than 15 minutes.	
Stretching	• Dynamic Stretch: A general warm-up consisted of 6 minutes of light-jogging on a treadmill at self-selected comfortable pace will be performed by participants before the DS intervention. DS will consist of bilateral dynamic stretches on the quadriceps, hamstrings, and plantar flexors. Each dynamic stretching movement will last for 30 seconds, with 20 seconds of rest in between, and 4 sets will be performed. Participants will be asked to achieve the highest range of motion possible for all dynamic stretches. For the quadriceps, participants will walk “butt kicks” that perform dynamic knee flexion and hip extension. For the hamstrings, participants will walk with high hip flexion with knee extended that causes the leg out in front of the body. For plantar flexors, participants stand facing a wall with their hands placed on the wall, and will push off or rebound from the wall to give the plantar flexors a dynamic stretch. • Static Stretch: The SS will also target the quadriceps, hamstrings, and plantar flexors. Each static stretching position will be held for 30 seconds, with 20 seconds of rest in between, and 4 sets will be performed. The SS will then be repeated on the opposite leg. For quadriceps, participants will flex the knee with using their arm to pull the foot towards the buttocks. For hamstrings, participants will flex the hip and place the heel on a 50 cm high platform, then reach forward with their arms towards the extended leg. For plantar flexors, participants will extend dorsiflexion while standing with keeping the feet flat on the floor and then leaning, supporting their body against a wall. • Control (Warm-up only): For the control session, only the general warm-up consisting of 6 minutes of light-jogging on a treadmill at self-selected comfortable pace will be performed. Each stretching protocol should take no longer than 15 minutes	Minimal risk-minor muscle soreness similar to mild physical activity

F2. Explain how the privacy and confidentiality of the participants' data will be maintained after study closure:

All data will be stored in a locked filing cabinet in a locked room. All data will be given a letter and number that is uniquely associated with participants. This code will not contain any partial identifiers (i.e. last four digits of your SSN) and will be stored in a separate locked office in a locked filing cabinet. No identifiers will be stored with the research data. Only those individuals with an active role in this study will have access to the research data and only the PI and Co-PI will have access to identifying information. When all participants complete active participants in the study and data collection is completed, the code will be destroyed. All appropriate measures to protect your private information will be taken.

F3. Explain how the data will be analyzed or studied and how the data will be reported

Data Analysis

- A written program (Matlab, v.7.6.9, The MathWorks Inc, Natick, MA) will be used to calculate the time-to-boundary (TTB) data. To calculate TTB measures, the foot will be modeled as a rectangle to allow for separation of the anterior-posterior (AP) and medial-lateral (ML) of center of pressure (COP). The COP ML position and velocity will be used to calculate TTB ML. If the COP ML is moving medially, the distance between COP ML and the medial border of the foot will be calculated. This distance will be then divided by the corresponding velocity of COP ML to calculate the time it would take the COP ML to reach the medial border of the foot if it were to continue moving in the same direction with no acceleration or deceleration. If the COP ML is moving laterally, the distance between COP ML and the lateral border of the foot will be calculated and divided by the corresponding velocity of COP ML. Thus, a time series of TTB ML measures will be generated. A time series of corresponding TTB AP measures will be similarly generated by determining the time it would take COP AP to reach either the anterior or posterior boundary of the foot.
- The distance scores (cm) for each direction of the star excursion balance test (SEBT) will be averaged over the 3 trials and normalized to leg length (reach distance/leg length x 100 = percentage of leg length). The normalized distances in each direction will then be summed for the test leg.

Statistical Analysis

A 3x2 (warm-up x time) Repeated measures Analysis of Variance (ANOVA) will be used in SPSS for Windows (version 16.0, Chicago, IL, USA) to identify any alteration in the dependent variables. The independent variables will be the three interventions (a general warm-up with dynamic stretching, a general warm-up with static stretching, and a general warm-up alone), and time (pre and post). Three separate ANOVA's will be performed on each set of dependent variables: range of motion measures (hip flexion, knee extension, and ankle dorsiflexion), SEBT measures (anterior, posterior-medial, and posterior-lateral), and TTB measures (the absolute minimum, mean of minimum samples, and standard deviation of minimum samples in the ML and AP direction). Post-hoc will be used to further evaluate any significant findings. The alpha level for determining significance will be set at $\leq .05$ for all calculations. Data will only be reported in aggregate form.

SECTION G: Benefits and Risk/Benefit Analysis

G1. Describe any benefits to the individual participants.
There are no benefits to you other than to further research.

G2. Risks to research participants should be justified by the anticipated benefits to the participants or society
1 Physical risks: Muscle soreness as the result of the testing (unlikely)
Musculoskeletal injuries such as muscle strain (unlikely)

2 Psychological, social risks: None

3 Protection of Physical Risks: to reduce the above risks, tasks practice will be performed prior to data collection to allow participants more familiar with each test. If participants feel any soreness or strain while participating in this study, please tell the investigators as soon as possible. Participants will you initial be provided care by investigators, who are all certified in first aid and CPR, and will then be referred to the Norris Health Center (student) for follow-up care or participants' personal physician (no-students) for follow-up care.

SECTION H: Subject Incentives/ Compensations

H1. Does this study involve incentives or compensation to the subjects?
[X] Yes

H2. Explain what (a) the item is, (b) the amount or approximate value of the item, and (c) when it will be given. For extra credit, state the number of credit hours and/or points
The awarding of extra credit and its amount is dependent upon your instructor. Please contact your instructor before participating if you have any questions. If extra credit is awarded and you choose to not participate, the instructor will offer an equitable alternative. Participants who complete all visits will receive $30 in gift card.

H3. If extra credit is offered as compensation/incentive,
Student may be compensated in the form of coursework extra credit if an instructor deems the research an extra credit opportunity

SECTION I: Deception/ Incomplete Disclosure (INSERT "NA" IF NOT APPLICABLE)

I1. Describe (a) what information will be withheld from the subject (b) why such deception/ incomplete disclosure is necessary, and (c) when the subjects will be debriefed about the deception/ incomplete disclosure.
NA

Appendix B

Informed Consent Form

UNIVERSITY OF WISCONSIN – MILWAUKEE
CONSENT TO PARTICIPATE IN RESEARCH

1. General Information

Study title:
The Effects of Static Stretching versus Dynamic Stretching on Lower Extremity Joint Range of Motion, Static Balance, and Dynamic Balance

Person in Charge of Study (Principal Investigator):
The Principal Investigator (PI) for this study is Jennifer Earl-Boehm, PhD, LAT. Dr. Earl-Boehm is a faculty member in the Department of Kinesiology and is the Director of the Athletic Training Education Program. The Co-PI on this study is Wenqing Wang. Wenqing is a Master's student in the Department of Kinesiology.

2. Study Description

You are being asked to participate in a research study. Your participation is completely voluntary. You do not have to participate if you do not want to.

Study description:
The purpose of this study is to examine the effects of two stretching techniques on range of motion in the ankle, knee and hip, and balance performance.

This study will help us learn more about which stretching technique might be best to prepare the individuals with hamstrings and calf muscle tightness for exercise. Also, the results could be used to design better rehabilitation protocols for improving balance.

The study is being done in the Neuromechanics Laboratory (Enderis 132A) University of Wisconsin-Milwaukee.

There will be 15 participants in this study and each participant. There will be 4 visits to the laboratory, each lasting about an hour.

3. Study Procedures

What will I be asked to do if I participate in the study?
If you agree to participate you will be asked to go to the Neuromechanics Laboratory (Enderis Hall, Room 132A) at University of Wisconsin-Milwaukee for 4 testing sessions.

- You will need to wear appropriate shorts and sandals, which are both provided by the laboratory. There will be 4 testing days each occurring between 48-96 hours apart.

<u>Screening Session</u>: You will be asked some questions about your history of previous leg injuries and your physical activity. We will measure your leg length, weight, and height. After that, there will be two screening tests:

Deep Squat Test: You will be asked to grab the dowel and press it over head with the feet shoulder width apart. Then you will be instructed to squat down as low as you can while keeping your heels on the floors. If you are unable to squat low while keeping your heels on the floor it means that you have tight hamstring and calf muscles, and you will be able to continue in the study. If you are able to squat low and keep your heels on the floor, it means you do not have tightness, and you are not able to continue in the study.

Active Knee Extension Test: You will lie on your back on an exam table with your hip bent and your leg resting on top of a bench. You will then try to straighten your knee all the way. A device called a fluid inclinometer will be used to measure the knee angle. If he knee angle is greater than 15° from the vertical position you will be included for the study. If it is not, it means you do not have hamstring tightness and you will not be included in the study (20 minutes)

Range of Motion: You will be measured the bilateral leg range of motion in the ankle by a tape measure and hip by a fluid inclinometer before and after balance tests. (10 minutes)

- Hip Flexion: You will lie on your back on an exam table. A tool to measure joint angle (fluid inclinometer) will be attached to a strap around your thigh. The investigator will then bend your hip with your knee bent, until a firm end feel is reached. Hip flexion angle will be then measured by the fluid inclinometer.
- Ankle Dorsiflexion: You will stand facing a wall approximately 3 inches away from the wall. One leg will be placed behind the other and used to maintain stability. Keeping the second toe, center of the heel and knee in line, and keeping the test heel firmly planted on the floor, you will lunge forward to try and touch the wall with your knee. If successful, you will move the foot you are standing on away from the wall until the knee can no longer touch the wall while keeping the heel on the ground. The investigator will use a tape-measure the furthest distance between your toe and the wall.
- Knee Extension: The AKE test, as described in the screening section, will be used to assess the knee extension range of motion. This test will not be repeated, as the measurement was made during the screening.

Balance Tests: Two balance tests will be performed *before* and *after* the stretching routine on each day.

- Static Balance: You will stand as still as possible on a force plate on one leg with your eyes closed for 10 seconds. You will be able to practice, and then we will collect 3 trials.

- Dynamic Balance: You will stand in the center of a "Y" shaped grid marked on the floor. You will need to maintain your balance on one leg while your opposite leg reaches to touch as far as possible along the 3 lines that extend from the center of the "Y". You will perform 3 trials in each direction with 30s rest between each trail. (10 minutes)

Stretching Protocols: You will perform three different stretching protocols during the study. Each one will be done on a different day that is 48-96 hours apart. Each day you will start with 6 minutes of light jogging at a self-selected pace on a treadmill. Then you will be stretching your quadriceps (front of your thigh), hamstrings (back of your thigh), and calf muscles during each different routine. Each stretching protocol should take no longer than 15 minutes

- Dynamic Stretch: For the quadriceps, you will perform walking "butt kicks" that include dynamically bending your hip and knee. For the hamstrings, you will walk with "high kicks" that bends the leg out in front of the body while keeping your knee straight. For your calf muscles, you will stand facing a wall with your hands placed on the wall, and will push off or rebound from the wall to give the calf muscles a dynamic stretch. Each stretching movement will last for 30 seconds, with 20 seconds of rest in between, and 4 sets will be performed. You will be asked to achieve the highest range of motion possible for all dynamic stretches
- Static Stretch: For the quadriceps, you will bend your knee using your arm to pull the foot towards the buttocks. For the hamstrings, you will bend the hip and place the heel on a 50 cm high platform, then reach forward with your arms towards your toes. For the calf, you will keep your feet flat on the floor and then lean in towards a wall. Each static stretching position will be held for 30 seconds, with 20 seconds of rest in between, and 4 sets will be performed. The SS will then be repeated on the opposite leg.
- Control (Warm-up only): For the control session, only the general warm-up consisting of 6 minutes of light-jogging on a treadmill at self-selected comfortable pace will be performed.

4. Risks and Minimizing Risks

What risks will I face by participating in this study?

Physical risks:
Muscle soreness as the result of the testing (unlikely)
Musculoskeletal injuries such as muscle strain (unlikely)

Psychological, social risks:
None

Protection of Physical Risks:
To reduce the above risks, you will be allowed to practice all tests prior to data collection until you feel comfortable with the task. If you feel any soreness or strain while participating in this study, please tell the investigators as soon as possible. You will you initial be provided care by investigators, who are all certified in first aid and CPR, and will then be referred to the Norris Health Center (student) for follow-up care or your personal physician (non-students) for follow-up care.

Risks to Privacy and Confidentially:
Since your private information will be collected for this study, there is always a risk of breach of confidentiality (less than 1%)

Protection of Risks to Privacy and Confidentially:
All data will be stored in a locked filing cabinet in a locked room. All data will be given a letter and number that is uniquely associated with you. This code will not contain any partial identifiers (i.e. last four digits of your SSN) and will be stored in a separate locked office in a locked filing cabinet. No identifiers will be stored with the research data. Only those individuals with an active role in this study will have access to the research data and only the PI and Co-PI will have access to identifying information. When all participants complete active participants in the study and data collection is completed, the code will be destroyed. All appropriate measures to protect your private information will be taken.

5. Benefits

Will I receive any benefit from my participation in this study?
There are no benefits to you other than to further research

6. Study Costs and Compensation

Will I be charged anything for participating in this study?
You will not be responsible for any of the costs from taking part in this research study

Are subjects paid or given anything for being in the study?
You may be able to earn extra credit in some of your courses. Participants who complete all visits will receive $30 in gift card.

7. Confidentiality

What happens to the information collected?
All information collected about you during the course of this study will be kept confidential to the extent permitted by law. We may decide to present what we find to others, or publish our results in scientific journals or at scientific conferences. Only the PI and Co-PI, will have access to the information. However, the Institutional Review Board at UW-Milwaukee or appropriate federal agencies like the Office for Human Research Protections may review this study's records.

The confidentiality of your data and information will be safeguarded as outlined in "Risks & Minimizing Risks" section under the "Protection of Risks to Privacy and Confidentiality" header.

8. Alternatives

Are there alternatives to participating in the study?

There are no known alternatives available to you other than not taking part in this study.

9. Voluntary Participation and Withdrawal

What happens if I decide not to be in this study?

Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee. If you choose to withdraw, we will use the information collected about you to that point. If you are a student, your refusal to take part in the study will not affect your grade or class standing.

10. Questions

Who do I contact for questions about this study?

For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Jennifer Earl-Boehm, PhD, LAT
Athletic Training Education Program
Pavilion, 367 PO Box 413 Milwaukee, WI 53201
414-229-3227

Who do I contact for questions about my rights or complaints towards my treatment as a research subject?

The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board
Human Research Protection Program
Department of University Safety and Assurances
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201
(414) 229-3173

11. Signatures

Research Subject's Consent to Participate in Research:

To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.

____

Printed Name of Subject/ Legally Authorized Representative

____ ____________________

Signature of Subject/Legally Authorized Representative Date

Principal Investigator (or Designee)

I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.

____ ____________________

Printed Name of Person Obtaining Consent Study Role

____ ____________________

Signature of Person Obtaining Consent Date

Appendix C

Screening & Medical History Questionnaire

Screening Criteria

☐ Yes ☐ No Are you between the ages of 18 and 45 years old?

☐ Yes ☐ No Are you current recreationally active (engage in some form of physical activity at least 30 minutes a day, 3-4 days of the week for the past 6 months)?

(Above questions must be YES, for participants)

Screening Exclusion Criteria

☐ Yes ☐ No Do you have a medical condition that may impair your balance performance (i.e. concussion, neurological impairments, etc.)?

☐ Yes ☐ No Do you participate in any of a proprioceptive or balance training in the past 6 months?

☐ Yes ☐ No Do you have lower extremity pain or injury in the past 6 month

☐ Yes ☐ No Do you have any surgery in the lower extremity in the past 6 month?

☐ Yes ☐ No Evidence or history of head injury or vestibular disorder within the last 6-months

(Above questions must be NO for all participants)

Exercise/Sporting Activity: ____

Average weekly participation (hours): __________

Active Knee Extension test

Left leg:	_______	_______	_______
Right leg:	_______	_______	_______

(The angle is greater than 15° or more from the ver tical position)

Deep Squat test

_______ Can squat down so the things are below horizontal while keeping the arms above the head and the trunk straight → Exclude

_______ Can NOT squat down so the things are below horizontal while keeping the arms above the head and the trunk straight → Include

Comments/Notes:

Appendix D

Recruitment Flyer

DO YOU HAVE TIGHT HAMSTRINGS AND CALF MUSCLES?

University of Wisconsin –Milwaukee
Neuromechanics Laboratories, END 132

Title: The Effects of Static Stretching versus Dynamic Stretching on Lower Extremity Joint Range of Motion, Static Balance, and Dynamic Balance

Purpose: The purpose of this study is to examine the effects of two stretching techniques on joint range of motion in the ankle, knee and hip, and balance performance.

Who can participant?

- Male and female (Ages 18 to 45)
- Recreationally active (30mins of moderate exercise 3-4 days /week)
- Feel tight in your hamstrings and calf muscles
- No lower extremity injury, concussion or balance disorders within the last 6 months
- No history of participating in balance training activities within the last 6 months

What will I do?

- Initial Screening: Active Knee Extension and Deep Squat tests (~5 min)
  Joint Range of Motion assessments (~5 min)
- Visit 1~3 (In 3 separate days): Balance assessments (~15 min)
  Stretching Protocol 1~3 (~15 min)
  Balance assessments (~15 min)
  Joint Range of Motion assessments (~10 min)

Compensation?

You may be able to earn extra credit in some of your courses.
Participants who complete all visits will receive $30 in gift card.

Questions?

Principal Investigator:
Jennifer Earl-Boehm, PhD, LAT
414-229-3227

Principal Investigator:
Wenqing Wang
414-520-5298

This research project has been approved by the University of Wisconsin-Milwaukee Institutional Review Board for the Protection of Human Subjects (IRB Protocol Number 13.309, approved on 03/06/2013)

Appendix E

Data Collection Sheet

University of Wisconsin –Milwaukee
Neuromechanics Laboratories, END 132

Gender: ________
Age: ________
Height: ________
Weight: ________
Leg length: ________

Shoe Size ___________________
_____Condition 1- Dynamic stretches
_____Condition 2- Static stretches
_____Condition 3- Control, warm-up only

Knee Extension (Active Knee Extension test)

	PRE			POST		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Left						
Right						

Hip Flexion test

	PRE			POST		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Left						
Right						

Ankle Dorsiflexion (Weight-bearing Lunge test)

	PRE			POST		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Left						
Right						

Star Excursion Balance test

	PRE			POST		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Anterior						
Posteromedial						
Posterolateral						

Time-to-boundary

	PRE			POST		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Mediolateral						
Anteroposterior						

Appendix F

Individual Data

Subject#	Gender	Age	Height	Weight	Leg Length	Shoe Size	Test leg	SLL	SRL	Sporting activity
1	f	32	167	57	85.5	9	R	33.33	35.33	Spinning, soccer
2	m	31	170	56	81	8	L	29.67	25.33	Running
3	m	23	180	83	91	9	L	36.33	20.00	Basketball
4	f	22	160	35	72	6	R	22.00	36.33	Running
5	m	23	179	60	95	8	R	35.00	54.00	Cycling, volleyball
6	m	23	184	75	94	11	R	18.67	29.00	Basketball, hockey
7	m	24	181	82	89.5	10	R	22.00	28.33	Soccer
8	m	23	178	76	81.5	9	L	48.33	35.33	Weight lifting, running
9	f	21	165	70	79	8	R	12.67	21.00	Hockey, volleyball
10	m	23	178	72	89.8	13	R	19.67	28.67	Jiujitsu
11	f	19	169	68	77	9	L	23.67	23.00	Volleyball, running
12	m	23	187.5	82	97	12	L	39.00	38.00	Swimming, bike
13	f	31	157	61	79.5	8	R	24.33	30.00	Running, swimming
14	f	26	167	68	87.5	9	R	35.00	46.00	Running, hockey
15	f	32	168	55	77.5	9	L	24.67	18.33	Walking
mean		25.1	172.7	66.7	85.1			28.29	31.24	
SD		4.3	9.0	13.0	7.5			9.41	9.87	

SLL=Screen Left Limb; SRL=Screen Right Limb

Subject#	SS-AKET-PRE	SS-AKET-PO	SS-HFT-PRE	SS-HFT-PO	SS-WBLT-PRE	SS-WBLT-PO	SS-SEBT-A-PRE	SS-SEBT-A-PO	SS-SEBT-PM-PRE	SS-SEBT-PM-PO	SS-SEBT-PL-PRE	SS-SEBT-PL-PO	SS_PR_TTB_ML	SS_PO_TTB_ML	SS_PR_TTB_AP	SS_PO_TTB_AP
1	40.00	25.00	121.00	124.67	5.57	7.13	69.82	72.01	112.59	110.64	102.85	103.12	0.93	1.01	2.74	3.01
2	40.67	26.00	103.33	105.33	5.87	7.70	76.58	80.58	111.32	122.67	97.82	109.26	0.93	1.09	2.15	2.58
3	34.67	24.67	133.33	138.67	12.23	13.03	75.16	79.34	101.28	109.01	94.40	100.18	1.95	1.85	4.78	4.35
4	33.67	21.33	155.67	145.67	10.17	10.07	77.59	80.51	103.89	110.23	92.45	99.72	1.05	0.97	2.69	2.32
5	52.00	48.00	141.67	144.67	9.53	10.33	74.14	75.44	107.54	108.91	94.11	98.42	0.52	0.41	1.31	1.48
6	29.67	21.33	139.00	142.67	9.60	10.70	83.79	87.91	119.29	120.71	118.05	122.41	0.88	1.05	2.58	3.43
7	25.33	19.33	125.00	123.67	5.07	6.20	75.38	80.41	118.92	123.54	113.93	120.04	1.18	1.19	3.29	3.70
8	42.00	37.33	125.00	124.67	8.87	9.60	91.00	92.52	124.79	126.58	120.94	124.46	1.19	1.72	3.42	3.67
9	16.67	10.33	128.00	132.33	7.03	8.53	77.47	87.22	112.45	121.14	103.38	110.55	0.98	0.89	3.28	2.49
10	29.33	19.67	122.67	127.00	10.33	11.30	80.36	89.76	120.97	121.60	110.43	114.48	1.05	0.92	2.32	1.98
11	16.00	4.00	138.33	150.33	11.50	11.93	87.49	90.78	120.69	126.23	113.72	123.46	0.97	1.11	2.98	3.17
12	34.00	33.00	116.33	121.67	10.00	10.47	71.82	71.68	102.58	105.81	94.40	93.23	0.54	0.71	1.53	1.30
13	31.33	23.33	138.33	140.00	2.67	2.90	66.29	65.07	108.09	105.58	103.02	102.77	0.76	0.66	2.34	2.23
14	40.67	37.33	131.67	130.33	9.63	10.73	70.78	72.27	105.07	107.05	99.73	101.49	1.12	1.02	3.40	3.44
15	18.67	17.00	136.00	145.33	3.47	3.57	76.56	79.91	116.56	121.20	107.74	118.71	0.77	0.80	2.17	2.18
mean	32.31	24.51	130.36	133.13	8.10	8.95	76.95	80.36	112.40	116.06	104.46	109.49	0.99	1.03	2.73	2.75
SD	10.19	11.04	12.39	12.21	2.95	2.94	6.60	8.10	7.52	7.92	9.28	10.44	0.33	0.37	0.86	0.87

Individual Static Stretching Intervention Data
SS=Static Stretching
AKET=Active Knee Extension Test
HFT=Hip Flexion Test
WBLT=Weight-bearing Lunge Test
SEBT=Star Excursion Balance Test
TTB=Time-to-boundary
A=Anterior
PM=Posteromedial
PL=Posterolateral
ML=Mediolateral
AP=Anteroposterior

Subject#	DS-AKET-PRE	DS-AKET-PO	DS-HFT-PRE	DS-HFT-PO	DS-WBLT-PRE	DS-WBLT-PO	DS-SEBT-A-PRE	DS-SEBT-A-PO	DS-SEBT-PM-PRE	DS-SEBT-PM-PO	DS-SEBT-PL-PRE	DS-SEBT-PL-PO	DS_PR_TTB_ML	DS_PO_TTB_ML	DS_PR_TTB_AP	DS_PO_TTB_AP
1	31.33	31.33	120.33	126.67	7.57	8.50	69.98	70.49	107.56	108.81	100.66	103.94	1.11	0.59	3.71	2.69
2	31.67	24.00	97.33	109.00	5.47	6.60	71.32	78.93	106.09	113.54	96.26	103.17	1.26	1.03	2.36	2.75
3	35.33	23.00	130.00	134.33	9.80	12.03	73.30	74.32	100.62	107.14	94.43	101.58	1.18	1.56	2.53	3.56
4	31.00	23.67	147.00	149.33	7.07	9.03	76.53	71.57	103.01	101.30	86.53	89.86	1.39	1.55	3.84	3.57
5	46.00	41.33	137.33	136.00	9.83	10.83	73.19	72.84	114.25	111.09	100.11	102.60	0.56	0.62	1.64	1.73
6	24.33	20.67	138.67	135.33	9.23	10.00	88.48	91.13	120.78	123.51	115.92	119.29	0.88	0.66	2.81	2.27
7	25.33	18.00	125.00	125.00	5.43	6.37	75.42	79.07	119.22	118.70	115.98	120.15	1.99	1.55	4.43	3.43
8	46.33	35.33	120.67	128.67	8.40	8.70	78.12	86.50	108.51	122.09	113.46	120.78	1.98	1.09	4.00	3.51
9	17.33	9.33	130.33	133.33	7.00	7.60	84.60	86.50	116.29	120.04	109.16	112.11	0.89	0.68	1.66	1.48
10	24.67	17.67	129.67	134.67	10.23	10.70	76.65	78.95	118.00	119.56	107.54	112.88	0.74	1.05	2.34	2.60
11	15.67	3.00	141.00	143.67	11.00	11.07	84.63	90.22	127.84	133.07	119.26	119.57	1.01	0.85	2.97	2.57
12	30.67	27.33	118.33	123.67	9.63	10.10	71.72	75.09	102.89	106.67	98.14	99.07	0.50	0.54	1.07	1.19
13	30.00	15.00	140.00	130.00	2.67	2.37	62.47	62.10	105.41	105.41	100.67	106.25	1.05	0.88	2.28	2.37
14	38.00	36.00	117.00	115.67	9.57	9.97	70.93	72.69	104.76	108.19	100.15	100.30	0.94	0.81	2.67	2.21
15	17.67	19.33	140.00	139.00	3.97	4.07	79.48	81.89	117.76	120.09	121.94	121.33	0.73	0.94	2.06	2.61
mean	29.69	23.00	128.84	130.96	7.79	8.53	75.79	78.15	111.53	114.61	105.35	108.86	1.08	0.96	2.69	2.57
SD	9.34	10.25	12.81	10.24	2.49	2.71	6.66	8.07	8.13	8.64	10.30	9.86	0.44	0.35	0.96	0.74

Individual Dynamic Stretching Intervention Data
DS=Dynamic Stretching
AKET=Active Knee Extension Test
HFT=Hip Flexion Test
WBLT=Weight-bearing Lunge Test
SEBT=Star Excursion Balance Test
TTB=Time-to-boundary
A=Anterior
PM=Posteromedial
PL=Posterolateral
ML=Mediolateral
AP=Anteroposterior

Subject#	CN-AKET-PRE	CN-AKET-PO	CN_HFT-PRE	CN-HFT-PO	CN-WBLT-PRE	CN-WBLT-PO	CN-SEBT-A-PRE	CN-SEBT-A-PO	CN-SEBT-M-PRE	CN-SEBT-M-PO	CN-SEBT-L-PRE	CN-SEBT-L-PO	CN_PR_TTB_ML	CN_PO_TTB_ML	CN_PR_TTB_AP	CN_PO_TTB_AP
1	36.67	29.67	119.67	124.67	8.10	8.47	70.57	70.41	114.70	114.54	104.64	107.64	0.61	1.58	2.94	4.52
2	39.00	23.00	95.67	110.33	6.13	6.67	69.34	74.81	110.66	118.89	101.89	106.67	0.90	1.19	1.78	2.34
3	25.67	23.33	136.33	124.00	12.10	12.60	69.82	72.82	105.49	106.34	97.73	98.61	1.78	1.46	5.30	3.82
4	26.67	15.33	146.00	145.33	10.60	11.93	82.31	85.83	104.58	110.28	94.26	96.44	1.29	1.25	2.97	3.50
5	53.00	39.00	139.33	144.67	9.23	9.83	69.72	70.42	107.30	106.98	100.11	102.25	0.98	0.83	2.15	1.70
6	34.67	27.67	130.00	136.67	8.90	10.27	84.54	87.73	115.11	118.62	117.55	119.26	0.84	0.82	2.38	2.61
7	28.33	16.00	129.33	128.67	6.13	6.53	69.39	72.33	109.98	116.16	111.17	122.50	1.09	1.01	2.37	2.65
8	38.33	32.33	128.00	127.67	8.33	8.77	91.08	93.09	119.35	122.58	115.99	122.45	1.43	2.33	4.50	4.57
9	25.33	21.67	121.00	124.00	5.63	6.63	83.29	85.27	115.70	118.44	107.26	111.56	0.67	0.70	2.10	2.05
10	31.00	25.67	120.33	123.00	11.03	11.80	83.22	90.09	118.30	120.16	116.44	117.15	0.79	0.75	2.00	3.20
11	17.00	3.00	144.33	144.67	9.77	11.83	87.23	89.61	125.97	130.48	122.55	126.80	0.74	1.20	2.33	3.09
12	26.33	20.33	124.33	121.33	9.30	10.07	72.41	77.29	109.24	107.63	100.72	98.73	0.67	0.86	1.51	1.59
13	29.00	26.67	132.33	132.67	2.97	3.03	67.34	64.86	104.78	103.90	100.25	100.88	0.77	0.68	2.95	2.63
14	46.00	40.00	125.33	127.33	9.20	11.10	69.52	69.75	96.95	101.83	92.57	97.83	0.87	1.01	2.74	2.63
15	25.67	19.33	135.67	140.00	4.03	4.50	80.60	81.51	116.22	115.70	116.17	119.18	0.77	0.85	1.49	1.93
mean	32.18	24.20	128.51	130.33	8.10	8.94	76.69	79.06	111.62	114.17	106.62	109.86	0.95	1.10	2.63	2.86
SD	9.21	9.36	12.28	10.14	2.60	2.91	8.07	9.02	7.30	7.87	9.42	10.57	0.33	0.44	1.05	0.93

Individual Warm-up alone Intervention Data
CN=Control
AKET=Active Knee Extension Test
HFT=Hip Flexion Test
WBLT=Weight-bearing Lunge Test
SEBT=Star Excursion Balance Test
TTB=Time-to-boundary
A=Anterior
PM=Posteromedial
PL=Posterolateral
ML=Mediolateral
AP=Anteroposterior

Appendix G

Linear Regression Analysis

1. Linear Regression of Range of Motion (ROM) and SEBT for Static Stretching Intervention

	Ankle Dorsiflexion ROM	Knee Extension ROM	Hip Flexion ROM
ANT	$r = 0.43$, $r^2 = 0.19$, $p = 0.11$	$r = 0.24$, $r^2 = 0.06$, $p = 0.40$	$r = 0.07$, $r^2 = 0.01$, $p = 0.80$
PM	$r = 0.15$, $r^2 = 0.02$, $p = 0.59$	$r = 0.35$, $r^2 = 0.12$, $p = 0.20$	$r = 0.15$, $r^2 = 0.02$, $p = 0.59$
PL	$r = 0.12$, $r^2 = 0.01$, $p = 0.67$	$r = 0.38$, $r^2 = 0.15$, $p = 0.16$	$r = 0.07$, $r^2 = 0.004$, $p = 0.82$

SEBT=Star Excursion Balance Test, ANT=anterior, PM=posteromedial, PL=posterolateral

2. Linear Regression of Range of Motion (ROM) and SEBT for Dynamic Stretching Intervention

	Ankle Dorsiflexion ROM	Knee Extension ROM	Hip Flexion ROM
ANT	$r = 0.36$, $r^2 = 0.13$, $p = 0.19$	$r = 0.50$, $r^2 = 0.25$, $p = 0.06$	$r = 0.34$, $r^2 = 0.11$, $p = 0.22$
PM	$r = 0.14$, $r^2 = 0.02$, $p = 0.61$	$r = 0.35$, $r^2 = 0.12$, $p = 0.20$	$r = 0.36$, $r^2 = 0.13$, $p = 0.18$
PL	$r = 0.05$, $r^2 = 0.002$, $p = 0.87$	$r = 0.50$, $r^2 = 0.25$, $p = 0.06$	$r = 0.20$, $r^2 = 0.04$, $p = 0.47$

SEBT=Star Excursion Balance Test, ANT=anterior, PM=posteromedial, PL=posterolateral

3. Linear Regression of Range of Motion (ROM) and SEBT for Warm-up alone Intervention (Control)

	Ankle Dorsiflexion ROM	Knee Extension ROM	Hip Flexion ROM
ANT	$r = 0.19$, $r^2 = 0.04$, $p=0.49$	$r = 0.34$, $r^2 = 0.18$, $p=0.21$	$r = 0.26$, $r^2 = 0.07$, $p=0.35$
PM	$r = 0.02$, $r^2 = 0.001$, $p=0.93$	$r = 0.42$, $r^2 = 0.17$, $p=0.12$	$r = 0.01$, $r^2 = 0.001$, $p=0.98$
PL	$r = 0.11$, $r^2 = 0.012$, $p=0.70$	$r = 0.36$ $r^2 = 0.13$, $p=0.18$	$r = 0.07$, $r^2 = 0.005$, $p=0.81$

SEBT=Star Excursion Balance Test, ANT=anterior, PM=posteromedial, PL=posterolateral

4. Linear Regression of gained Range of Motion (ΔPre-Post ROM) and the improvement SEBT (ΔPre-Post reach distance) for Static Stretching Intervention

	Ankle Dorsiflexion ΔROM	Knee Extension ΔROM	Hip Flexion ΔROM
ANT	r= 0.42, r^2= 0.17, p = 0.12	r = 0.21, r^2= 0.04, p = 0.45	r = 0.13, r^2= 0.02, p = 0.64
PM	r = 0.19, r^2= 0.04, p = 0.49	r = 0.18, r^2= 0.03, p = 0.52	r = 0.02, r^2<0.001, p = 0.96
PL	r = 0.03, r^2= 0.001, p = 0.93	r = 0.25, r^2= 0.06, p = 0.37	r = 0.19, r^2= 0.04, p = 0.51

SEBT=Star Excursion Balance Test, ANT=anterior, PM=posteromedial, PL=posterolateral

5. Linear Regression of gained Range of Motion (ΔPre-Post ROM) and the improvement SEBT (ΔPre-Post reach distance) for Dynamic Stretching Intervention

	Ankle Dorsiflexion ΔROM	Knee Extension ΔROM	Hip Flexion ΔROM
ANT	r = 0.37, r^2= 0.14, p = 0.17	r = 0.14, r^2= 0.02, p = 0.61	r = 0.49, r^2= 0.24, p = 0.06
PM	r = 0.10, r^2= 0.01, p = 0.71	r = 0.29, r^2= 0.08, p = 0.30	r = 0.57, r^2= 0.32, p = 0.03
PL	r = 0.36, r^2= 0.13, p = 0.19	r = 0.38, r^2= 0.15, p = 0.15	r = 0.31, r^2= 0.10, p = 0.26

SEBT=Star Excursion Balance Test, ANT=anterior, PM=posteromedial, PL=posterolateral

6. Linear Regression of Range of Motion (ΔPre-Post ROM) and the improvement SEBT (ΔPre-Post reach distance) for Warm-up alone Intervention (Control)

	Ankle Dorsiflexion ΔROM	Knee Extension ΔROM	Hip Flexion ΔROM
ANT	r = 0.14, r^2= 0.02, p=0.61	r = 0.27, r^2= 0.07, p=0.34	r = 0.06, r^2= 0.004, p=0.83
PM	r = 0.41, r^2= 0.17, p=0.13	r = 0.48, r^2= 0.23, p=0.08	r = 0.33, r^2= 0.11, p=0.23
PL	r = 0.03, r^2= 0.001, p=0.92	r = 0.39 r^2= 0.16, p=0.15	r = 0.17, r^2= 0.03, p=0.54

SEBT=Star Excursion Balance Test, ANT=anterior, PM=posteromedial, PL=posterolateral