Biomechanics of the Lower Extremity Dynamic Balance Tests: Kinematics and Electromyography Analysis of the Y-Balance Test and the Star Excursion Balance Test

by

Mariam Ahmad Abu Alim

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Approved by

Mary E. Rudisill, Co-Chair, Wayne T. Smith Distinguished Professor of Kinesiology
Gretchen D. Oliver, Co-Chair, Associate Professor of Kinesiology
Wendi H. Weimar, Professor of Kinesiology
Joni M. Lakin, Associate Professor Department of Educational Foundations, Leadership, and Technology

Abstract

Lower extremity dynamic balance is maintained through a sequence of segmental motions within a kinetic chain. Reaching dynamic balance tests measure the distance in which one can extend his/her center of gravity over the base of support in different directions, for the purpose of quantifying the limitations of postural control. Two related tests were used interchangeably to assess the dynamic control through the performance of a dynamic single-leg balance tasks; the Star Excursion Balance Test (SEBT) and the Lower Quarter Y Balance Test (LqYBT).

Comprehensive analyses, including assessment of muscular activity and kinematics, were used to better identify differences between the performance of SEBT and LqYBT. Thus, the purpose of this study is to examine the differences between the SEBT and LqYBT, regarding reaching distances; hip and knee frontal and sagittal plane kinematics; muscle activation profiles of the gluteus medius, adductor magnus, hamstring, and quadriceps; and the gastrocnemius musculature of the stance leg. Also, this research examined if sex (male or female), hip, and knee passive joints range of motion affect the achieved reaching distances.

Twenty-six healthy, recreationally active, participants volunteered for this study (15 females [age *M* = 21.7, *SD* = 1.4 years] and 11 males [age *M* = 21.7, *SD* = 2.28 years]). Lower extremity muscle activation was obtained during the forward reaching phase of the LqYBT and the SEBT tested directions. The frontal and sagittal plane kinematics of the hip and knee were calculated at the maximum reach of the anterior, posteromedial, and posterolateral directions of the two balance tests. Hip and knee passive range of motion were also performed to indicate if they had an influence on the achieved reaching distances.

Significant differences in reaching distances were observed in the posteromedial and the posterolateral directions between the LqYBT and the SEBT. The activation of the gluteus medius were significantly higher in female participants preforming the LqYBT compare to male participants in the anterior and posterolateral reaching directions. Female participants showed a significant increase in the activation of the adductor magnus, and the quadriceps muscles, performing the posteromedial reaching direction of the LqYBT compare to males. The performance of the LqYBT was characterized with a significantly increased hip abduction/adduction range of motion compare to the SEBT in all three reaching directions. Significant differences in hip flexion between the two balance tests were indicated for all three reaching directions. Significantly increased knee abduction/adduction range of motion were observed in the posteromedial and posterolateral reaching directions of the LqYBT compared to the SEBT.

The current study contributed to the body of knowledge that addresses the differences between the LqYBT the SEBT, and attempted to establish a comprehensive analysis of the differences between female and male test performances. The current study demonstrates that female participants had an increased amount of hip and knee abduction/adduction performing the LqYBT compared to the SEBT. The findings suggest that the LqYBT dynamic balance test is more sensitive in determining female hip and knee control. It was concluded that the two balance tests significantly differ, thus using them interchangeably in the filed or transform outcomes between the two tests might not be appropriate when assessing the postural control of healthy recreationally active populations.

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Chapter I: Introduction

Smooth, coordinated movement patterns are a fundamental element of performing daily activities (Berg, Williams, Holliday, & Wood-Dauphinee, 1992) and competing in sports environments (Butler, Southers, Gorman, Kiesel, & Plisky, 2012). Efficient movement patterns require a sensory detection of movement, sensorimotor integration, and the execution of the relevant musculoskeletal activation patterns. Assessing these parameters utilizes the evaluation of static and dynamic postural control or balance (Flanagan, 2012; Ives, 2013). The accomplishment of efficient movement patterns through the combination of static and dynamic balance depends on the synergy between the muscular, articular, neural systems and the surrounding environment.

To maintain postural stability during motion, the body combines inputs from the visual, vestibular, and proprioceptive systems. Together these systems provide the body with information regarding the relationship to the horizon, the relative position of segments with adjacent segments and the relative position of the body in space (Hrysomallis, 2011; Flanagan, 2012). These inputs are then translated in the central nervous system (CNS) to establish balance and neuromuscular control through the executed motor program. Optimum motor programming helps to produce efficient neuromuscular stabilization during functional movement patterns (Winter, Patla, Frank, 1990; Bressel, Yonker, Kras & Heath, 2007; Hrysomallis, 2011).

Inefficient neuromuscular stabilization leads to compensations and substituted movement patterns, which result in excessive mechanical loading that increases the risk of injuries. Lack of stabilization alters joint kinematics, muscle activation patterns, and muscle co-activation synergies, which impacts performance and leads to joint overloads. Research studies have reported that poor neuromuscular stabilization that reflects balance is associated with lower extremity injuries among the athletic and recreationally active populations (Rauh, Kaminski, & Underwood, 2006; Hrysomallis, 2007; Paterno et al., 2010; Gribble, Hertel & Plisky, 2012; Fullam et al., 2014).

Balance is either static or dynamic (Flanagan, 2012; Guskiewicz et al., 1996; Ives, 2013). Static balance is the ability to maintain the body's center of gravity over the individual’s base of support in the presence of a perturbation (Hrysomallis, 2011; Flanagan, 2012). Dynamic balance is the capability to sustain or restore a constant position during locomotion and make posture adjustments to maintain the desired movement trajectory or return to a position following a perturbation (Hrysomallis, 2011; Flanagan, 2012).

Regarding these two categories, many balance assessments have been developed, where the individual is set in a certain position with an applied perturbation, and the examiner evaluates the amount of body sway, either subjectively (visually) or objectively through the use of different sophisticated equipment (Hrysomallis, 2007, 2011; Flanagan, 2012). There are a variety of balance test protocols currently used. These balance test protocols are categorized based upon the method of challenge; different bases of support (i.e., feet next to each other, two feet tandem, single leg stance), surface over which the test is performed (i.e., firm, soft); or proprioceptive inputs such as eyes open, closed, or one eye open at a time (Dallinga, Benjaminse & Lemmink 2012). Balance assessments are valuable in the evaluation of injury risk based on abnormal movement patterns, asymmetry, and dynamic body control (Dallinga, Benjamins & Lemmik, 2012; Gribble, Hertel & Plisky, 2012). They have been applied to clinical settings, research studies, as well as in the athletic and recreational arena.

The Star Excursion Balance Test (SEBT) and the Y- Balance Test (LQYBT) are among the most common and well-established balance assessments. Both tests have a high interrater and intrarater reliability, validity, cost-effectiveness, and do not require sophisticated equipment and/or technology to conduct (Gribble & Hertel 2003; Robinson et al., 2007; Hoch et al., 2010; Coughlan et al., 2012; Lokie et al., 2013; Chimera et al., 2015; Kang et al., 2015).

The SBET is a combination of the unilateral stance balance tests and multidirectional opposite leg reach tasks. The SEBT is performed in eight directions, each direction presents a unique balance challenge and requires different dynamic coordination. In each direction the participants have to balance on one leg and reach as far as possible with the opposite leg, without compromising their postural stability (Gary et al., 1995; Gribble, 2003). Forty-eight reach tasks are required to complete the SEBT (3 reaches each in 8 directions performed bilaterally) posing a significant limitation because it is time-consuming to administer (Fullam Caulfield, Coughlan, & Delahunt, 2014). Fullam and colleagues also reported that there is redundancy in the test objective, in addition to the absence of a standardized test protocol for the SEBT performance (Hertel et al., 2006). As a result, researchers designed a test protocol and standardized the SEBT performance (Hertel, Braham, Hale & Olmsted, 2006; Robinson et al., 2008; Gribble et al., 2012). The results of the studies generated a modification version of the SEBT, called the Y-Balance test (YBT).

The lower quarter of the YBT (LqYBT) has the same excursion performance of the SEBT, but there are just three reaching directions, including the anterior, posteromedial, and posterolateral directions. The modified reaching directions of the LqYBT reflected the objective of the test more accurately with less redundancy and more disparity in the reaching distance data (Hertel et al., 2006; Hertrl, 2008; Robinson et al., 2008; Gribble et al., 2012). Moreover, the researchers standardized the LqYBT test protocol performance (Fullam et al., 2014; Gribble et al., 2012).

Both tests have been used interchangeably to assess balance, assuming that the modified version of the SEBT and the LqYBT should produce comparable results in the anterior, posteromedial, and posterolateral reaching distances. Although, researchers have found kinematic and reaching distance differences between the SEBT and the LqYBT (Coughlan, Fullam, Delahunt, Gissane & Caulfield, 2012; Fullam et al., 2014). Participants reached farther in the anterior reach direction when performing the SEBT than the anterior reach direction of the LqYBT (Coughlan, et al., 2012). The results of this previous study were consistent with the kinematic patterns associated with the two test performances (Fullam et al., 2014; Fullam et al., 2012).

Several performance predictors or factors that may influence balance test performance among healthy, physically active individuals have been investigated for the SEBT and the LqYBT, separately. Among the predictors that were significantly correlated with performance of the SEBT included anthropometric characteristics (body height and leg length), body mass index, sex, lower extremity strength, and sagittal plane kinematics (ankle dorsiflexion, hip flexion angle and trunk position) (Hertel et al., 2006;

Hertrl, 2008; Robinson et al., 2008; Gribble et al., 2012; Ku, Abu Osman, Yousof & Abas, 2012).

Purpose

The purpose of this study is to examine the differences in the performance outcomes between the SEBT and LqYBT, regarding reaching distances, hip and knee kinematics, selected muscle activation profiles, that each test elicits, across sexes of a healthy, recreational active individuals. Also, this research examined if hip and knee passive joints range of motion may account for differences in test reach distance performance.

Significance

Although the LqYBT is a modified version of the SEBT, the validity of using the two tests interchangeably, or in combination to examine the postural control (balance) has been questioned by researchers. Additionally, there is limited research addressing differences in execution between the two tests. Identifying performance strategies and compensations for restricted movement patterns of each test could be a more useful component of injury screening and a priority in retraining during risk management strategies. Detecting the differences between the SEBT and the LqYBT may be of value to sport therapists and other professionals working in the field as it is possible to better evaluate and detecting changes in balance that could lead to lower extremity injury.

Research Questions

This research study investigated the differences between the SEBT and the LqYBT through answering the following research questions:

- To what extent are there differences in muscle activation between SEBT and the LqYBT in all three tested directions? Are there any differences between males and females?
- To what extent are there differences in hip and knee joint kinematics between SEBT and the LqYBT in all three tested directions? Are there any differences between males and females?
- To what extent are there differences between the SEBT and the LqYBT in reaching distance in all three tested directions? Are there any differences between males and females?
- What is relationship between passive hip and knee joints range of motions and the performance of the SEBT and LqYBT in males and female participants?

Hypothesizes

Hypothesis 1. Average activation amplitudes of the selected muscles will significantly differ between the SEBT and the LqYBT in all three tested directions (anterior, posteromedial, and posterolateral) during the forward reach, and will significantly differ between males and females.

Hypothesis 2. Hip and knee joint kinematics will significantly differ between the SEBT and the LqYBT in all three reach directions, and will significantly differ between males and females.

Hypothesis 3. Reaching distance in all three directions will significantly differ between the SEBT and the LqYBT, and will significantly differ between males and females.

Hypothesis 4. There will be a positive correlation between passive hip and knee joints range of motion and LqYBT reaching distance in males and female participants.

Limitations

Limitations in this study are listed below:

Limitation 1. Data for this study will be collected on a small sample of healthy recreational active college students.

Limitation 2. Data for this study will be collected in two-dimensions only (in the frontal and sagittal plane of motion).

Limitation 3. Two-dimensional lower extremity joint kinematics will be collected only from the hip and the knee joint.

Delimitations

Delimitations of this study are listed below:

Delimitation 1. Hip and knee joint range of motion will be measured passively; thereby, greater values are expected in compression to joints range of motion during the performances of the SEBT and the LqYBT (active range of motion).

Delimitation 2. The kinematic data of the hip and the knee joints and the sEMG activity will be measured during the phase of the forward reach. The forward reach phase starts from the beginning of the forward progression of the reaching leg and ends when the leg reaches the farthest point.

Delimitation 3. Data collection will occur in a controlled laboratory setting inside the Auburn University Sports Medicine and Movement Laboratory.

Definitions

Kinematics. A branch of mechanics that address movements of the body segments linearly and in an angular motion in terms of displacements, velocities, and accelerations, without the description of its mass or the forces acting on it.

Surface EMG (sEMG). A technique to perceive the electrical activity of the muscle, in which electrodes are placed on (not into) the skin overlying the belly of a muscle.

Passive range of motion (pROM). Passive range of motion (pROM) is the amount of motion of a certain joint when the joint is moved by an exterior force or an examiner.

Star Excursion Balance Test (SEBT). Star Excursion Balance Test (SEBT) is a clinical assessment of dynamic postural stability that involves unilateral stance while attempting maximal reach with the most distal part of the opposite leg in three different directions: anterior, posteromedial, and posterolateral.

Lower Quarter Y Balance Test (lqYBT). Y Balance Test is a clinical assessment of dynamic postural stability that involves unilateral stance on a one inch elevated central block, while pushing a rectangular reach indicator with the most distal part of the opposite leg in three different directions: anterior, posteromedial, and posterolateral.

Static balance. Static balance is the ability to maintain the body's center of gravity over the individual’s base of support in the presence of a perturbation.

Dynamic balance. Dynamic balance is the capability to sustain or restore a constant position during locomotion and make posture adjustments to maintain the desired movement trajectory or return to a position following a perturbation.

Kinetic Chain. Kinetic chain is a description of a chain of events of the body segments that take place in order for a movement to occur.

Chapter II: Literature Review

The purpose of this study is to examine performance differences between SEBT and the LqYBT indicated by the sagittal and frontal plane hip and knee joints kinematics, selected muscle activation profiles and sex, among healthy, recreational active individuals. Furthermore, this study is being conducted to examine if sex and hip and knee passive range of motion (pROM) may account for differences in test reach-distance performance and between tests. The following section will provide a review of the literature discussing these two assessments and how they measure balance.

Balance

Balance is an integral and fundamental component of all forms of locomotion. It is defined as the ability to maintain center of gravity within an individual's base of support and to sustain body equilibrium following a perturbation (Alexandrov, Frolov, Horak, Carlson-Kuhta & Park, 2005). Balance involves a complex process, requiring the synergy of different body systems. This process incorporates the integration of several neurological pathways and necessitates continuous afferent sensory feedback from all of the mechanoreceptors (Irrgang, James, Susan, Whitney, & Cox, 2010; Comerford & Mottram, 2001; Winter, 1995; Guskiewicz & Perrin, 1996).

Postural control

According to Winter (1995), balance reflects the outcomes of the inertial process and is considered a generic description of the postural control mechanisms that are used to avoid falling. Posture describes the alignments of body segments with reference to each other and the position of the body in space (i.e., position of the body to the environment) at a given time (Ives, 2013). Postural control can be addressed not only as static equilibrium but also as the ability to move while controlling the body's center of gravity to provide a stable position against perturbations. Maintaining postural equilibrium depends on a process that utilizes the integration of the visual, vestibular, and proprioceptive sensors to provide information from the surrounding environment to the central nervous system. The control process of postural equilibrium requires sensory recognition of the locomotion, sensorimotor integration, in addition to the efficient musculoskeletal responses (Guskiewicz et al., 1996; Ives, 2013).

Postural control is elicited under two conditions; when the body is disturbed or when the individual anticipates a disturbance. Also anticipatory postural control is translated in two basic forms. When the body is disturbed, feedback is provided by the visual system to elicit a response. A reaction to the upcoming or expected environmental conditions or changes in body segment positions is elicited based on the visual feedback provided in combination with past experiences the individual has encountered. For example, before stepping on a slippery surface, the trunk may stiffen. When an individual anticipates a disturbance, anticipatory postural adjustments (APA) are made to ensure postural control (Ives, 2013). APA represents the stabilization of a certain segment or the whole body prior to the execution of a task in order to withstand the postural movements (Ives, 2013).

Leonard (1998) reported four characteristics of the APAs during voluntary movements. Firstly, the tendency to minimize body displacement during voluntary motion is either reactionary or anticipatory. Secondly, APAs are adaptable to the nature of the movement in terms of condition and contexts. Thirdly, is that the ability to improve adjustments through learning experiences. And lastly, APAs are influenced by individual’s sociological state (i.e., intent and emotions).

Ives (2013) provided an example of the APA mechanism. The participant was asked to pull a fixed lever fixed to a wall, contracting the biceps brachi, as a response to an auditory stimulus. Reaction time of elbow flexion was 200 milliseconds (ms) while reaction time for the gastrocnemius was 125 ms. Thus, reflecting a pre-activation of the gastrocnemius in the attempt to provide a stable base to counteract the pulling forces of the elbow flexion. From this experiment, it was concluded that motor programming of an action is divided into two parts of stabilization and task objective motor activity. It was also concluded that the APA mechanism may be innate, but also influenced by the environmental and task conditions, and individual characteristics (Ives, 2013).

The control theory. To further explain the mechanism of postural control, Reeves and colleagues proposed the application of control theory from a system engineering perspective (Reeves, Narende, & Cholewcki, 2007). According to the control theory, the postural control mechanism depends on the expected task that is represented as the output. The mechanism works to properly position the body’s center of gravity either when the goal is to maintain static equilibrium or dynamic equilibrium involving movement. The control mechanism is represented as a continuous circuit between the central nervous system and the musculoskeletal system (Narende & Cholewcki, 2007).

The interaction between the central nervous system and various receptors translated in the musculoskeletal system elicits the desired output (motion). The output is evaluated against the expected task providing feedback to the nervous system via proprioceptors. The feedback mechanism is developed via the amalgamation of the visual, vestibular, muscular, and tendon receptors, in addition to the joint mechanoreceptors and skin receptors. The feedback provided is used to sense any alterations in posture, as well as correct and/or counter center of gravity to maintain balance. Regarding the obtained feedback, an appropriate motor program is then developed within the central nervous system, and signals are sent again to the musculoskeletal to be translated (Narende & Cholewcki, 2007; Miller, 2012).

Based on the control theory, the stability of the body is defined by the ability to maintain a static position or follow a stable trajectory, or to return to a static equilibrium following perturbation. Stability has a binary quality that only describes the body as stable or not stable, without ranging in the degrees of stability (Reeves et al., 2007). If the body succeeds in accomplishing the task, the smooth and coordinated responses to perturbations are necessary for maintaining balance. Factors that impede balance and stability can be potentially indicated in the central nervous system (CNS), where faulty motor programming signals sent to the musculoskeletal system, or the inputs required for the task may exceed the capability of the musculoskeletal system to achieve the task. Alternatively, providing faulty proprioception that inhibits the intrinsic properties of the musculoskeletal system, will alter the process by either providing incorrect or delayed information to the CNS (Devlin, 2000; Miller, 2012).

Thus, the efficient processes of inputs gathered from the visual, vestibular, and proprioceptive systems to recognize body position (either between segments or in space) and the systems integration with the sensorimotor system in the CNS establish body balance and neuromuscular control for the movement, leading to the execution of the appropriate motor program. The evaluation of the developed and translated motor program can be achieved by analyzing the quality of movement through the performance and robustness. The performance address how quickly the body can regain equilibrium either by returning to the desired position or trajectory following a perturbation. Robustness refers to the amount a perturbation the body can withstand (Miller, 2012).

Mechanisms of balance. The mechanisms of balance depend on the amalgamation of the sensory organization, muscles synergy and co-activation, and sensorimotor integrations. Sensory organization is the process that assesses APA strategies through determining optimal timing, direction, and amplitude in the muscular skeletal system. This process is depending on feedback obtained through visual, vestibular, and proprioceptive inputs. Visional sensory feedback provides information about the orientation of the eyes and head in relation to the surrounding environment. The vestibular system provides information that indicates the gravitational, linear, and angular accelerations of the head within the surrounding environment (Ives, 2013). Proprioception is the cumulative neural inputs that sense the position of the segment and the changes during motion, as well as provides the information to the central nervous system. Body position is sensation largely mediated through the muscular mechanoreceptors. Joints motion and position are indicated through the ligamentous and articular mechanoreceptors (Purves, Augustine, Fitzpatrick, Katz, LaMantia, McNamara, & Williams, 2001).

In the present of motion, joint environment undergoes a disturbance where the joint soft tissues and the articular tissues experience stress and deformations. This results in elongation, compression, traction, or tension tissue distortions. Causing reflex-mediated responses that regulate the relationship between the agonist and antagonist muscle activation ratio and joint positioning. The reflex-mediated responses are generated through the sensation of joint movement or displacement innervated by the mechanoreceptors, and assessed by the thermoreceptors and pain receptors, that are located throughout the skin, muscles, joints and bone (Lephart et al., 2000; Lephart et al., 1998). Mechanoreceptor is a sensory neural receptor that is activated by mechanical pressure or distortion of the tissue, generating neural impulses that are send to the CNS in the form of an action potential. Each provides impulses from peripheral mechanoreceptors that are conducted to the CNS as a response to a particular mechanical stress, associated with different lengths of excitement, and at a different threshold (Guskiewicz & Perrin, 1996, Purves et al., 2001).

Kinetic Chain. The human body is a series of segments linked together via joints creating a kinetic chain. The link characteristic of the kinetic chain is addressed as “chain reaction” which referrers to the sequence of segmental motion. The movement of a segment will affect the movement of the adjacent segment in either direction, proximal to distal or distal to proximal (Kendall, McCreary, Provance, Rodgers, & Romani, 2005).

The kinetic chain concept is defined as an open kinetic chain (applies to non-weight-bearing activities) and close kinetic chain (applies to weight-bearing activities). The close kinetic chain expresses the body motion when the distal body segment is fixed on the ground, or the motion is resisted by sufficient resistance, as the stance leg when walking or the upper extremity when weightlifting. An open kinetic chain motion is characterized when the most distal segment moves freely, as when kicking the ball. In general terms, the lower extremity and the lumbopelvic hip complex acts in a closed kinetic chain; whereas the upper extremity is functioning as an open kinetic chain (Starkey & Ryan, 1996).

When evaluating the locomotion of individuals, the examiner considers the application of the kinetic chain concept. Any alteration in the alignment or trajectory of any joint or segment will affect the alteration in the whole kinetic chain (Nguyen & Shultz, 2009). These alterations will cause the body to accommodate for the falling link by changing the body mechanics, resulting in increased energy expenditure, muscle fatigue, pain, and alerted motor-programing that lead to poor movement patterns (Nguyen & Shultz, 2009).

The efficiency of neuromuscular control provides optimal synergy activation between the agonists, antagonists, and stabilizing muscle groups that develop the appropriate movement sequence of the kinetic chain. Any form of motion requires forces to be generated, absorbed, and transferred throughout the kinetic chain. The transferred forces should follow a sequence of the reduction and stabilization to produce the optimal movement patterns (Winter, 1995; Kibler, Press, & Sciscia, 2006; Miller, 2012).

A decrease in neuromuscular efficiency within the kinetic chain ultimately leads to injury and joint degeneration. Alterations in the kinetic chain alignment affect the quality of the locomotion and thus faulty movement patterns (Zajac, Neptune, & Kautz, 2002). Faulty movement patterns directly impact the muscular activation and co-activation systems, preventing efficient muscular action. Alteration in muscle activation may cause a slower response from the prime movers, while the co-activation and alteration in the synergists and stabilizer activation ratios. These compensatory muscular actions alter the muscle force-couple relationship, length tension relationship, and joint kinematics (Clark & Lucett, 2010; Miller, 2012; Ives, 2013).

Joints range of motion and neuromuscular control. Kinetic chain movement efficiency is also dependent upon the available joint range of motion (ROM). Any restriction caused by soft tissues (i.e., ligaments, tendons, muscles) could result in dysfunction and/or bony deformity (Starkey & Ryan, 1996). Joint ROM is defined as the available range of motion that the joint can accomplish, and it is expressed in degrees (Norkin & White, 2009).

Adequate muscle length represents the muscle length-tension relationship. For optimal force production, the muscle fibers should be under sufficient tension. This tension is developed within the sarcomere unit, where the relationship between myofilament of the actin and myosin determines the muscle length. Three tension lengths can be developed within a muscle that depends on joint position active, passive, and the resting length. The optimal tension that muscle can produce is when the muscle is in the resting length, which is developed when the actin and myosin myofilaments are symmetrically connected. When a muscle is shortened which is referred to as active tension, the actin and myosin myofilament are overlapping as the muscle is fully contracted the myofilament cannot slide to produce any further tension (i.e., force). In lengthened muscle that is referred as passive tension, the myofilaments are fully stretched from each other, and minimal interaction between the actin and the myosin is established which lack sufficient generation of any further tension (i.e., force) that is required for proper movement or stability (Bunton et al., 1993; Starkey & Ryan, 1996).

Furthermore, the appropriate movement sequence of the kinetic chain also depends on the optimal synergy activation between the antagonistic muscle groups reflecting the efficient joint range of motion and neuromuscular control. Agonist muscles are responsible for the primary movement of a joint, while antagonist muscles are responsible for countering and perform the opposite movement of the agonist. In order for the joint motion to occur the antagonist muscles must relax to allow the movement of the agonist muscles (reciprocal inhibition). If the nervous system does not send an inhibitory impulse to the antagonist muscle to relax and instead an activation impulse is received, the antagonist muscle activation will counter and resist the action of the agonist muscle; thus, the target joint would not move (Bunton et al., 1993; Starkey & Ryan, 1996).

The synchronized contraction of agonist and antagonist muscles is co-contraction, and it is defined as simultaneous activation of antagonistic muscles crossing a joint. The main purpose of muscle co-contraction is to assess the ligament function in providing joint stability, provide resistance to joint motion, and equalize the pressure distribution over the articular surface (Hurd & Snyder-Mackler, 2007). The smooth, balanced, and continued motion of the body is secured because of the generated activation/inhibitory reflex loop between the antagonist-agonist muscle groups.

Moreover, the muscular length-tension relationship between the antagonistic muscles is considered a key element in maintaining postural stability and avoiding injurious forces on the involved joints. Disturbed length-tension relationship between agonist and antagonist muscle groups is defined as muscle imbalance. Muscle imbalances are designated as impairment in the co-activation between an over-activated muscle, subsequently tightened and shortened, and other elongated, inhibited weak muscles, leading to alterations in movement patterns as the muscle imbalance around the active joint or joints cause changes in forces exerted and its distribution over the joint surface.

Hip alignment. The importance of providing proximal stability for efficient distal mobility refers to the impact of providing a stable base that the upper or lower extremities can anchor to produce and transfer the generated energy. This stable base is the lumbopelvic-hip-complex, which is constructed over the gluteal muscles and encloses the pelvis and the torso (Oliver, 2012). Thus, the control of the pelvic alignment and strength is essential in excursion of controlled and balanced movement patterns throughout the kinetic chain (Kibler, Press, & Sciascia, 2006). The stabilization of the pelvis and torso over the weight bearing leg is primarily provided by the gluteal muscle group. The gluteal muscle group provides postural stability by the eccentric contraction to resist generated momentum, and mechanically provide the control of excessive range of motion (Comerford & Mottram, 2001).

The gluteus medius provides frontal plane stability for the pelvis during walking and locomotion. Additionally the gluteus medius (Gmed) is a hip abductor that maintains level and stable pelvis during single leg weight bearing activities and performance phases (i.e. stance phase of the gait). Weakness in the Gmed may result in the Trendelenburg pattern, where an exaggerated sideward thrust of the supporting hip and a drop of the pelvis on the opposite side, alters knee joint alignment and increases the risk of overuse injuries and anterior cruciate ligament (ACL) noncontact injuries (Dallinga et al., 2012). Gmed is a fan shaped muscle that originates from the outer surface of the ilium between posterior and middle gluteal lines and inserts at the femur in the posterolateral surface of the greater trochanter. Moreover, the fan shape of the muscle from the insertion is divided to three parts where the muscle fibers extend to the anterior, middle, and posterior directions. Each directional fiber group is responsible for a specific function and has its own nerve innervations. The anterior fibers oriented almost vertically from the anterior iliac crest to the head of the greater trochanter are responsible for the abduction and internal rotation of the hip. The middle fibers are vertically oriented and initiate the abduction of the hip during stance. Whereas, the posterior fibers run parallel the neck of the femur, and tend to position the femoral head into the acetabulum, thus providing stabilization (Earl, 2005; Heller, 2003; Presswood, Cronin, Keogh, & Whatman, 2008).

Knee alignment. The knee complex, consisting of the tibiofemoral and patellofemoral joints, is a tenuous structure that depends on soft tissue structures to control the forces transmitted through the joint with a lack of bony support; thus, challenging the stability of the joint (Madeti et al., 2015).

The primary muscles that cross the knee are the quadriceps, hamstrings, and gastrocnemius, accounting for almost 98% of the total cross-sectional area of all knee musculature (Escamilla, 2001). When the quadriceps, hamstrings, and gastrocnemius contract, they produce additional shear and compressive forces within the joint articular surface, and the magnitude of the applied load depends on the knee flexion angle (Tang et al., 2001; Riemann et al., 2013; Escamilla et al., 2008; Flanagan et al., 2004; Escamilla, 2001). Consequently, lack of muscular strength initiates inefficient muscle activation patterns that lead to an excessive tibiofemoral shear force (Longpre et al., 2015; Escamilla, 2001; Escamilla et al., 2010). The contribution of the quadriceps, hamstrings, and gastrocnemius muscles in knee joint stability is addressed by resisting external joint excursions. Any alteration in the activation of these muscles may impact this stability (Stastny et al., 2015; Henriksen et al., 2013; Henriksen et al., 2007; Winby et al., 2009). Knee joint stability can be assessed by the antagonistic relationship between the hamstrings and the quadriceps. Whereas, the dynamic stability to the knee joint depends on the sufficient coordination and co-activation between the hamstrings and quadriceps, thus protecting the knee (Rosene et al., 2001).

Balance assessment of neuromuscular efficiency is greatly important when it comes to the evaluation of risk injuries based on abnormal movement patterns, asymmetry, and dynamic body control (Dallinga, Benjamins & Lemmik, 2012; Gribble, Hertel & Plisky, 2012). Balance tests involve feedback, input, and output; and have been referred to as the tests of neuromuscular control, due to the evaluation of these systems as one unit. Multiplane balance excursion tests assess the neuromuscular efficiency of the lower extremity, in addition to the evaluation of the objective range of motion, and individual’s limits of stability. Individual’s limit of stability is defined as the range outside an individual’s base of support, where he/she can move without losing control of the center of gravity (Clark & Lucett, 2010; Miller, 2012).

Typical laboratory assessment for balance and stability, include static single leg stance tests performed on force plates, have been addressed to have only moderated ability of evaluating postural stability deficits associated with lower extremity injuries (McKeon & Hertel 2008). Moreover, in a study conducted by Hrysomallis and colleges (Hrysomallis, McLaughlin & Goodman, 2007) showed overall a weak correlation between the static balance test and dynamic balance test values. Concluding that static balance test performance may not be reflective of a dynamic balance test performance and the attempt to infer dynamic balance ability based on static balance ability is not advisable Hrysomallis et al., 2006). Therefore, instrumented static postural stability assessments benefits in assessing the deficits of lower extremity risk of injuries are limited, and they lack in the dynamic component, coordinating postural control and sway evaluation in the same measure, a process that mimics everyday activities and sports performance. Furthermore, confounded by the availability of laboratory settings and force platforms (Fullam et al., 2014).

Reaching tests balance assessments

Reaching dynamic balance tests measure the distance in which one can extend his/her center of gravity over the base of support in different directions, for the purpose of quantifying the limitations of postural control (Flanagan, 2012). These tests provide significant challenges to the neuromuscular and proprioception systems through the combination of range of motion and positioning of the lower extremity joints, flexibility, muscular strength, and postural control (Chimera et al., 2015; Hesari et al., 2012; Fullam et al., 2012; Clark et al., 2010; Gribble et al., 2012; Gribble & Hertel, 2003). Star Excursion Balance Test (SEBT) and the (LqYBT) are considered to be the two most popular dynamic reaching balance tests. Both are used to determine the dynamic balance capabilities of the healthy and athletic populations (Gribble et al., 2003; Robinson et al., 2007; Hoch et al., 2010; Coughlan et al., 2012; Lokie et al., 2013; Chimera et al., 2015; Kang et al., 2015). Both tests have a high reliability and validity. These assessments are also cost-effective and do not require sophisticated equipment and technology to perform. The assessment of dynamic balance is easily applied in clinical and applied settings (Gribble et al., 2012).

Gary (1995) emphasized the importance of using functional movement tests that mimic the objective of the task being tested. The SBET is a combination of the Unilateral Stance Balance test and multidirectional Opposite Leg Reach Task. Each direction has unique balance challenges and requires different dynamic coordination postural control strategies in the correct plane of motion (Gary et al., 1995; Gribble, 2003). Eight reaching directions have been determined for the SBET, with a reference to the stance leg. The directions were described as anterior, anterior/lateral, posterior/lateral, posterior, posterior/medial, medial, anterior/medial, medial rotation, and posterior/medial. The test requires the participant to reach as far as possible in each direction without losing balance and stability while returning to the start position (the reaching foot next to the stance). Also, for the test to be successful the individual has to lightly touch the farthest point with the most distant part of the extending leg. If the participant rests and touches heavily with the reaching foot to regain balance, or fails to remain stable in the stance leg position, with no shifting or lifting during the trial, the trial is considered unsuccessful and has to be redone. The obtained reach distance values of the SEBT are used as an index of dynamic postural stability (i.e. better dynamic postural stability is associated with a further reach) and have been used: (a) in comparing injured and non-injured limbs (Delahunt, Monaghan & Caulfied, 2006); (b) to determine the effects of training (Filipa, Bynrned, Paterno, Myer, & Hewett, 2010; Bouillon, Sklenka, & Driver, 2009); (c) for rehabilitation purposes (Hale, Hertel,

& Olmsed-Kramer, 2007); (d) to demonstrate the impact of medical and athletic interventions such as using athletic tape (Delahunt, McGrath, Doran & Coughlan, 2010; Aminaka & Gribble, 2008); (e) to determine effectiveness of joint braces (Hardy, Huxel, Bruker & Nsesser, 2008); (f) to evaluate foot orthotics (Sesma, Mattacola, Uhl , Nitz & McKeon, 2008; Olmsted & Hertel, 2004), and (g) to objectively determine the impact of fatigue on dynamic postural control (Gribble, Hertel, & Denegar, 2007).

Gary and colleagues (1995) also suggested that additional assessments, other than reaching distance, can be obtained from the performance of the SEBT, such as the number of completed reaching trials within a certain time frame, the number of completed trials until failure, and the time required to complete a series of reaching trials in each direction individually. Additionally, the assessment of range of motion of the joint in a specific plane of motion (sagittal, frontal, or transverse) during the SEBT has also been proposed as an outcome component of the lower extremity functional control profile (Gray et al., 1995).

The original SEBT as described by Gray and colleagues (1995) underwent significant modification and changes over the years, however the fundamental components and descriptions of the original form were maintained (Robinson & Gribble,2008; Gribble, Hertel, 2003). Despite all the changes and modifications, the SEBT is a single leg stance combined with a multidirectional reaching task that is completed simultaneously and assesses dynamic postural stability. The initial evaluation of the SEBT was conducted to determine the reliability of the reaching direction and the rotational motions. Kinzey & Armstrong (1998) examined the reliability of four diagonal directions of the SEBT (anteromedial, posteromedial, anterolateral, and posterolateral). The researchers reported a range of 0.67 to 0.87 interclass correlation coefficient (ICC) of the selected diagonal reaching directions. Reliability of the SEBT diagonal reaching directions (right anterior, left anterior, right posterior, and left posterior) have also been examined and reported to be high for all reach directions (ICC = 0.84 to 0.97; Lanning, Uhl, Ingram, Mattacola, English, & Newsom, 2006). Different reach directions and reaching combinations of the SEBT have been found to have overall a good to high reliability (Bressel, Yonker, Kras, & Heath, 2007; Sawkins et al. 2007; Plisky, Rauh, Kaminski, & Underwood, 2006).

Although the reliability of the SEBT was well established, the number of trials reported in the research studies were numerous, averaging three trials in each of the eight directions bringing the total to 48 recorded trials preformed bilaterally. The inconvenience of the required number of trials to accomplish the SEBT tasks and the associated difficulty to compare the results between the studies, lead the researchers to investigate the correlations between the reaching directions in attempt to reduce the number of test directions (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). The anterior, posteromedial, and posterolateral SEBT reaching directions of the eight original SEBT reaching directions, reflected the objective of the test more accurately with less redundancy and more disparity of the reaching distance data between the tested directions (Hertel et al., 2006; Hertrl, 2008; Robinson et al., 2008; Gribble et al., 2012).

The attempts to further increase the efficiency of the SEBT, researchers examined the sufficient number of trials needed in each direction. Robinson and colleagues (2008) and Munro and Herrington (2010), found that the SEBT reaching distance and kinematic values of the lower extremity stance limb standardized by the fourth trial. The studies concluded that giving the participants four practice trials in each direction of the SEBT is sufficient for the standardization of the test performance. Moreover, to allow for a valid comparison between participants and studies, Gribble (2003) normalized the reach distance for each direction by the tested leg (stance leg) length or by body height. Although both normalization methods reported to be valid, stance leg length had a stronger correlation for the percentage protocol reported.

Though researchers tested variables and settings that could increase the validity and reliability of the SEBT as mentioned previously, further concerns were addressed in terms of standardizing the performance of the SEBT between test trials for both clinical and research studies. One of major concerns that might limit the accuracy of the SEBT outcomes is the amount of pressure the participants applied on the ground at the furthest reaching distance in the assigned reaching direction (Fullam et al., 2014). Thus, an instrumented device was developed called the Y Balance Test (LqYBT) that mimicked the SEBT three reaching directions. The LqYBT is designed by connecting three polyvinylchloride pipes on a raised block, where the participant performs a stance leg during the performance. The participant then directs motion into the anterior posteromedial and posterolateral angles, mimicking the three significant reaching directions of the SEBT. Each pipe is marked in 5-millimeter increments. The reaching direction distance is achieved via a sliding the block that the participant pushes along the pipe with the reaching leg. The sliding block remains at the pipe, and the farthest distance is obtained at the point where the block stops (Fullam et al., 2014; Gribble et al., 2012). The reliability of the LqYBT has been established (Plisky, Gorman, Butler, Kiesel,Underwood & Elkins, 2009); Shaffer, Teyhen, Lorenson, Warren, Koreerat, Straseske, & Childs, 2013; Faigenbaum, Myer, Fernandez, Carrasco, Bates, Farrell, Ratamess, & Kang, 2014). Plisky et al (2009) reported a good to excellent interrater reliability (intraclass correlation coefficient [ICC] of .99 to 1 with 95% confidence intervals [95% CI] ranging from .92 to 1) and intrarater reliability (ICC of .85-.91 with 95% CI ranging from .62 to .96). In addition, the reliability of the LqYBT was evaluated by two experts and the participants included fifteen healthy soccer players.

Shaffer and colleagues (Shaffer et al., 2013) examined the reliability of the LqYBT using multiple raters with a larger sample size of 64 service members (53 males, 11 females) actively conducting military training. The study was conducted over multiple days, and the results indicated a good interrater reliability with ICC equal to .85 to .93 (95% CI, .75 - .96) and test-retest reliability with ICC was equal to .80 to .85 (95% CI, .68 - .91). In a more specific reliability test of the LqYBT, researchers examined the interrater reliability of the observer error and for performance error (Faigenbaum, 2014). Observer error was associated with the raters observation and scoring the same participant simultaneously, while performance error was associated with raters observing the same participant on the same day but at different times. The reported ICC was greater than .995 for observer error measurement and for the performance error measurement was ($0.907 \leq \text{ICC} \leq 0.974$), concluding an excellent reliability for both.

Although the development of LqYBT was based on the directions of the SEBT, researchers have found that the two tests significantly differ in the anterior reaching distance. Participants of the two studies scored higher on the anterior reaching distance performance of the SEBT in comparison with the LqYBT (Fullam et al., 2014; Cuoghlan et al., 2012). From a kinematics perspective, differences between the two tests were also investigated (Fullam et al., 2014). This study examined the lower extremity sagittal plane angular displacement of the stance leg (i.e., dominant leg) in 29 healthy young adults, 15 males and 14 females. Participants' reaching distance for each direction of the SEBT and LqYBT tests were measured using a 3-D motion analysis system. The researchers reported statistically significant differences for the anterior reaching distance between the SEBT and the LqYBT, as participants reached further when performing the SEBT. Kinematically, hip joint sagittal plane angular displacement in the anterior reach direction differed statically between the two tests. During the performance of the

LqYBT, the hip flexion angle at the maximum reach point was (*M* = 27.94^{o} , *SD*= 13.84$^{o)}$, when compared with SEBT hip flexion angle *(M* = 20.37^{o,}, *SD* = 10.64^{o}).

When analyzing the robustness of the SEBT, neuromuscular control has been determined by measuring each of the reaching distances achieved for the test directions (Norise & Trudelle-Jackson, 2011). The further the reaching distance by an individual, the better neuromuscular control he/she possesses. Researchers also evaluated neuromuscular control of the SEBT and the LqYBT by investigating the kinematic factors of the tests performance, through the measurement of the proper joint angular displacements of the lower extremity and lumbopelvic-hip complex muscular strength, activation patterns, and muscle co-activation ratios (Robinson & Gribble 2008; Filipa, Byrnes, Paterno, Myer, & Hewett, 2009; Norise et al., 2011; Hesari, Golpaigian, Ortakand, Nodehi, & Nikollaidis, 2012; Kang et al., 2015). Moreover, a knowledge of muscle activation as indicated through the electromyographic (EMG) quantification, and contributes to the understanding of the neuromuscular control during dynamic weight bearing activities (Norise et al., 2011). It was suggested that a threshold of muscle EMG amplitude ranging from 40% to 60% of maximal voluntary isometric contraction (MVIC) was indicative of a strengthening stimulus, for example, as to resist or counter a generated force (Andersen, Magnusson, Nielsen, Haleem, & Poulsen, 2006). The EMG amplitudes less than 25% MVIC could be considered reflective of stabilization (Vezina & Hubley-Kozey, 2000).

The case of proximal stability demands during the performance of the SEBT was addressed in a study conducted by Norise and his colleagues (2011). The investigators carried out a study that investigated the hip and thigh muscle activity during the excursion of the SEBT as indicators of sagittal and frontal plane stability. The results of this study indicated that the postural stability in the frontal plane was represented by the gluteus medius and showed an EMG amplitude of 38% MVIC in the anterior and 22% MVIC in the posteromedial reaching directions. These amplitudes indicated that the gluteus meduis muscle was activated to maintain appropriate postural control through maintaining a level pelvis on the stance leg. As reported previously muscle activity lower than 40 % of MVIC in functioning as a stabilizer in the plane of motion (Andersen et al., 2006; Vezina et al., 2000). Additional muscles of the gluteus maximus and vastus lateralis were also examined for their contributions to the sagittal plane postural stability. The activities of these two muscles did not differ among the three reaching directions (i.e., anterior, medial, and posteromedial) of the SEBT suggesting that the participants used similar movement patterns in the execution of all reaching directions. Moreover, it was reported that there were no differences in the reaching distances of the three tested directions. The results also addressed that the gluteus maximus amplitudes measured in all three directions were in the range of 21% to 25% MVIC, reflecting that glut maximums were serving as a pelvic a stabilizer.

Studies that investigated muscle strength, activation patterns, and co-activation in association with the performance of the SEBT and the LqYBT attempted to provide evidence that these tests can be used as screening tests for neuromuscular control and indicate functional deficits related to the prediction and discrimination of the musculoskeletal injuries. Researchers have investigated the impact of fatigue protocols on the achieved reaching distances and explained the results using kinematic analyzes of the participants' performances (Gribble, Robinson, Denegar & Buckley, 2004; Gribble, Robinson, Hertel & Denegar; 2009). The authors reported a decrease in the SEBT reaching distances and associated lower extremity sagittal plane joint angular displacements at the hip and the knee joints after fatiguing. Although these two studies did not include electromyographic analysis of the associated muscles, it was suggested that due to fatigue the proximal muscle activation patterns might have been altered causing a decrease in range of motion at the knee and the hip, leading to decreases in reaching distance (Gribble et al., 2004; Gribble et al., 2009).

The predictor factors that contribute to the performance of the SEBT have also been investigated (Hesari, 2012). These researchers found that hip muscular strength was positively correlated to the performance of the SEBT. The results revealed a co-activation of the rectus femoris and hamstring during the excursion of all the three reaching directions of the SEBT. The activation of the rectus femoris muscle was higher during the anterior reach direction. However, it was noted that the participants were allowed to move their upper bodies freely while performing the test; thus, possibly explaining the high activation of the rectus femoris during the anterior reaching direction. During the anterior reaching trials, the participants leaned backwards, extending their trunk in order to maintain balance. This trunk positioning placed the body's center of gravity behind the flexed stance leg knee, creating increased knee joint flexion torque. To maintain stability, the knee flexion torque is countered by the activation of the knee extensors muscles, quadriceps or its equivalent (Perry & Burnfiled, 2010; Hesari et al., 2012). Moreover, the stabilization of the knee joint was indicated by the increased activation of the vastus lateralis during the medial and the posteromedial reaching direction of the SEBT, to counter for the created varus torque (Hesari et al., 2012). During the two posterior reach directions, high hamstring muscle activity was related to the need to counter the increased hip flexion torque. Increased hip flexion angle due to the demands of the trunk leaning forward, resulted in increased eccentric hamstring activation to maintain balance. Lateral reaching directions of the SEBT required external hip rotation and adduction. Thus, lateral reaching directions were found to be associated with the increases in biceps femoris muscle activation (Hesari et al., 2012).

Sex Differences Between the SEBT and the LqYBT. A research study conducted by Delahunt, Chawke, Keller, Murphy, Prendiville, Sweeny and Patterson (2013), examined the postural stability of young female athletes who had previously undergone anterior cruciate ligament reconstruction (ACL-R), using the SEBT. The results indicated a decrease in the reaching distance of the posteromedial and on the posterolateral reaching direction of the SEBT in the ACL-R, in comparison to a sex-matched uninjured control group. The results indicated no differences in the anterior reaching direction for the SEBT. The authors used kinematic analysis to show that SEBT reaching distance could be achieved using different movement strategies. Similarities in the anterior reaching distance of the SEBT between the two study groups were obtained using kinematics data from the CODA motion capture system, reflective markers, and force plates. The kinematic analysis indicated that ACL-R group performed the anterior reaching task of the SEBT with less sagittal plane hip and knee flexion angles, but had more ipsilateral hip adduction. These mechanics simulated the Trendelenburg position that provided a lengthening of the contralateral limb leading to increases in the anterior reach. As the control group achieved similar anterior reaching distances by increased hip and knee flexion angles (Delahunt et al., 2013).

Differences between males and females in several dynamic and functional tests have been associated with differences in movement patterns within their performance (Robinson & Gribble 2008; Chimera, Smith, & Warren 2015). Therefore, it is an important factor to consider when evaluating the dynamic stability and interpreting the test results. Researchers concluded that a potential main factor for sex differences was due to anthropometric discrepancies. As the average height and leg length of male participants were higher than female participants.

Additionally, the impact of anthropometric characteristics in the SEBT performance of young and healthy males and females has resulted in great performances in males in all eight directions (Gribble & Hertel, 2003). However, after normalizing the reaching distances by body height and by the length of the stance leg, the differences between the sexes were not present. This supported the use of limb length as the normalizing factor (Gribble & Hertel, 2003).

Differences in the SEBT normalized scores between males and females have also been found (Gribble, Robinson, Hertel, & Denegar, 2009). The researchers investigated the impact of different fatigue protocols on dynamic stability, and determined if there were any differences between young healthy males and females. The initial scores of the SEBT showed that females reached further in the anterior, medial, and posterior directions than males. Similarly, females performed the anterior and posterior reaching directions with a significantly higher average of knee flexion angles, 4 degrees and 5 degree respectively. After applying fatigue protocols, the differences between the sexes became more consistent (Gribble et al., 2009). Similar results were found in the study of Fullam, Caulfield, Coughlan, and Delahunt (2014), where they reported differences in the performance of the SEBT kinematic patterns between males and females. Female participants had a greater hip flexion range (29.10° ± 4.24°) than men (11.43° ± 4.24°) in the anterior direction reach direction of the SEBT (Fullam et al., 2014). Moreover, the kinematic results suggested better activation of the vastii muscles in females.

In a large cohort study of 200 Division I athletes conducted by Chimera, Smith and Warren (2015), including 102 males and 92 females, differences in a dynamic postural control functional movement screen (FMS) performance between sexes were also indicated. The study examined the effect of injury and sex on FMS and LqYBT performance in this collegiate athletic population, and reported that although there were no significant differences between female and male athletes, females had smaller differences in scores between the two limbs when demonstrating the anterior reaching direction of the LqYBT. Also, females had a better performance on the FMS that tested flexibility and balance but had lower performance on the core strength tests. The authors concluded and recommended that sex differences should be considered and tested as a covariate when conducting the LqYBT and FMS screening (Chimera et al., 2015).

The impact of neuromuscular control as assessed by SEBT and LqYBT in terms of determining injury risks in males and females has also been reported. Plisky, Rauh, Kaminski and Underwood (2006), conducted a study to examine if SEBT reach distance and composite scores were associated with the risk of lower extremity injury among male and female high school basketball players. The results of this study indicated that females had lower composite scores than males, and only the female athletes with a SEBT composite reach distance less than 94.0% of stance leg length were 6.5 times more likely to have a lower extremity injury. The researchers suggested that differences between males and females in the evaluation of the neuromuscular control and predicting risk injury could be demonstrated by the SEBT reaching distances and composite scores (Plisky et al., 2006).

Inherent gender differences in the LqYBT performances have also been indicated in the literature. Gorman and colleagues conducted a study where high school athletes' postural stability were assessed using the LqYBT (Gorman, Butler, Rauh, Kiesel & Plisky, 2012). The investigators examined the impact of participating in multiple sports or a single sport on LqYBT performance. The results indicated no difference in LqYBT reaching distances as well as in the composite scores between multi-sport athletes and single-sport athletes. However, male athletes outperformed female athletes for the posterolateral and posteromedial reaching directions, and for the composite score. These results were also in agreement with Teyhen et al. (2014) who reported that male athletes performed better on the lower extremity LqYBT than female athletes. In conclusion, it does appear that significant gender differences do exist on the LqYBT and SEBT, which makes it appropriate to conduct studies where both sexes are considered and analyzed, and efforts are continued to generate normative data that is sex specific (Gribble et al. 2009; Gorman et al. 2012).

Chapter III: Methodology

The aim of this study was to evaluate males and females while performing the Star Excursion Balance Test (SEBT) and the lower quarter Y Balance Test (LqYBT). The evaluation included kinematic and electromyographic data of males and females. The role of this chapter is to outline and describe the methodology. Sections written to describe the methodology are the following: (a) participants, (b) setting, (3) instrumentation, (4) design and procedures, and (5) data analysis.

Participants

Twenty-six physically active (15 females and 11 males) Auburn University students volunteered to participate in this study. To be eligible for participation and before inclusion, potential participants answered a Health Screening Questionnaire (See Appendix A). The participant inclusion criteria for this study was: (a) age between 19 and 35 years old, (b) no pain, injury, or surgery within the last six months, (c) recreationally active at least 3 hours per week, and (d) they felt that they could safely and successfully complete the assessments. The participants were excluded if they did not meet the inclusion criteria and/or are allergic to adhesive tape, if they were pregnant, and/or if they suffer from any central or neurological conditions, or were experiencing a cold/sinus infection or inner ear infection or inner ear dysfunction. Participants signed an Informed Consent document approved by the Auburn University Institutional Review Board (see Appendix B).

Setting

Data collection took place in a controlled laboratory setting inside the Sports Medicine & Movement Laboratory within the School of Kinesiology at Auburn University. This location possesses the space and equipment necessary to fulfill the objectives of this study.

Instrumentation

Y Balance Test (LqYBT). A commercially available Y Balance Test (Move2Perform from Evansville, Indiana) was used to assess the participants' dynamic balance. Specifically, the LqYBT Lower Quarter Protocol (LqYBT) was used.

Star Excursion Balance Test (SEBT). The test was constructed by attaching three strips of measuring tape to the floor. The first strip of tape was oriented anteriorly forward, the next two strips of tape were attached to the end of the first tape at 135 degrees, each in the posteromedial and posterolateral direction. The angle between the posteromedial and posterolateral was 90 degrees. The chosen reaching direction of the test were determined based on previous research (Plisky et al., 2006; Hertel et al., 2006).

Anthropometrics measurements. Standard measuring tape was used to obtain the participants' stance leg (dominant leg) length. The leg length was used to normalize the reaching distance of the SEBT and the LqYBT (Gribble & Hertel2003). Leg length was measured from the bony landmark of the anterior superior iliac spine to the medial malleolus (Gribble & Hertel, 2003; Coughlan et al., 2012).

Two-dimensional kinematics. Two-dimensional kinematics of the frontal and sagittal plane of the hip, and knee were obtained using two digital video cameras (GL2 Canon camcorder - GL2 NTSC, from Canon, Lake Success, New York, USA) recorded at 30 frames per second. Ten markers (14mm retro-reflective markers, MKR-6.4©, B&L Engineering®, Tustin, California, USA) were used to assist with kinematic calculation, increase accuracy, and allow for better comparison between participants. Using markers for two-dimensional kinematic analysis have been reported to increase the inter and intra-reliability of joint centers in comparison to unmarked, manual digitization (Bartlett et al., 2006; Bahamonde & Stevens 2006; Elliott et al., 2006). Markers were attached on each participant's dominant side. All cameras were calibrated to ensure the accuracy of the 2D kinematic measurements obtained from a single camera for each view. Calibration settings included camera positioning and a referenced calibration object. Cameras were positioned on tripods leveled horizontally so that the optical axis was perpendicular to the plane of motion. All digital video footage was recorded without optical zoom to standardize the camera position among participants (Dawson & Herrington 2015). Camera one was positioned to capture the frontal plane, and camera two was positioned to capture the sagittal plane of the participants. Both cameras were three meters from the participant's position in the center of the SEBT test. Similar studies reported positioning cameras three to four meters from the participant is appropriate for 2D kinematic analysis (Kagaya, Fujii & Nishizono, 2015; Dingenen, Malfait, Nijs, Peers, Vereecken, Verschueren, & Staes, 2015; Gwynne & Curran, 2014).

Surface electromyography (sEMG). Surface electromyography (sEMG) data were obtained using the Biopac system EMG (MP150, BIOPAC Systems Inc., Santa Barbara, California, USA). Disposable, Ag/AgCl contact area (11 mm) surface electrodes (EL503, BIOPAC Systems Inc.) were connected to Dual Wireless EMG BioNomadix Transmitter. Analog signals were analyzed through Acqknowledge 4.4 software (Biopac

System Inc., USA). EMG data were filtered using: Bandwidth = 10-500 Hz, Sampling = 1000 Hz, and signals were rectified using root mean square error (RMSE). Specific locations of the electrodes are described in Appendix (D).

Digital goniometer. An electronic goniometer (iGaging 35-310-G, Digital protector/Goniometer, China), with a measuring range of 0 degrees to 360 degrees, was implemented to measure passive range of motion (pROM). Error of measurement is less than 0.5 degrees with a resolution of 0.05 degrees, and 3V of battery power. Prior to data collection, the goniometer was calibrated to the manufacturer's recommended standards to ensure the accuracy of the measurements (Prakash et al., 2015; Diaz & Martinez 2014). Test interrater reliability for administering the passive range of motion were tests calculated. The investigator and two experts in the field performed the passive range of motion to determine investigator’s intrarater reliability. Inrarater and interratere reliability of the passive hip and knee joints range of motions was examined in a group of six (three females and three males) healthy aged between 20 and 26. All motions were measured in each subject three times per joint by each of the two physical therapists and by the investigator. Intra-rater showed an excellent reliability of .973, interclass correlation coefficients (ICCs) ranged from .946 to .993. Inter-rater reliability showed an excellent reliability of .985 ICCs ranged from .961 to .995.

Design and Procedures

All testing occurred during two separate data collection sessions with the following purposes: (a) baseline leg length measurements; (b) baseline pROM measurements; and (c) kinematic and electromyography. A minimum of 24 hours and no more than 72 hours separated the two data collection sessions. Balance test order was randomly assigned to the data collection session. During the first meeting, participants completed the Health Screening Questionnaire (see Appendix A) and signed the Institutional Review Board approved Informed Consent document (see Appendix B). The first meeting also included baseline measurements of leg length and pROM, and test performance. The second meeting included only baseline pROM measurements and test performance. Balance tests were performed barefoot while wearing shorts and a t-shirt. This attire allowed unobstructed access to the anatomical landmarks needed for the range of motion and kinematic measurements (Fullam et al., 2014). Leg length was measured on the participant’s dominant leg. Dominant leg was determined as the preferred leg used to kick a ball (Fullam et al., 2014).

Next, pROM of hip flexion, hip extension, hip abduction, hip adduction and knee flexion were measured. Passive range of motion measures of hip flexion was obtained with the participant in the supine position with hip extended and knee flexed, thus allowing the examiner to passively flex the hip. Extending the knee during the test will limit the hip flexion range of motion by placing the biceps femoris on stretch (Starkey & Ryan, 2002). Hip extension range of motion was obtained with the participant prone with hip and knee extended, which allowed the examiner to move the participant’s limb into hip extension while keeping the knee extended (Norkin & White, 2009).

Hip abduction pROM was performed with the participant supine with hip and knee extended. The examiner passively abducted the hip by placing one hand on the lower leg (i.e., under the ankle) to prevent internal external rotation of the limb and slide the limb laterally (Norkin & White, 2009). To obtain hip adduction pROM, the participant was supine with the hip and knee extended. Then the examiner passively adducted the hip by placing one hand on the lower leg (under the ankle) to prevent rotation of the limb, and slide the limb medially. The end-feel of pROM was sensed when the attempt to further adduct the hip resulted in lateral pelvic tilting, rotation of the pelvis, and /or trunk lateral flexion (Norkin & White, 2009).

Knee flexion pROM was obtained with the participant supine on the table. The examiner flexed the hip joint approximately 90° and placed one hand on the ankle to passively flex the knee. The end-feel of the knee flexion sensed as resistance to further knee flexion or when further knee flexion resulted in increased hip flexion (Norkin & White, 2009).

After baseline pROM measurements were completed, the participants' skin was prepared for the placement of the sEMG electrodes. Skin preparation included shaving, exfoliating with a water-based gel, and lightly abrading the skin with alcohol (Criswell, 2010; Earl & Hertel, 2001). Once the skin was prepared, surface electrodes were placed on the following muscles: gluteus medius, adductor magnus, rectus femoris, biceps femoris, and gastrocnemius (see Appendix D & F).

Following sEMG electrode placement, manual muscle tests (MMT) were performed in order to obtain a maximum voluntary isometric contraction (MVIC) of each muscle of interest. The MVIC was then used to normalize all recorded sEMG data. Three MMTs were performed on each of the selected muscles. Each MMT was held for 3 seconds.

Gluteus medius MVIC testing was performed with the participant lying on their non-dominant leg side. The non-dominant knee was flexed with the contralateral hip in a neutral position. Participants actively abducted their dominant leg while resisting a downward manual pressure applied just above the ankle. Participants were encouraged to keep their knee extended and toes pointing forward to elicit maximal contraction of the gluteus medius (Kendall, McCreary, Provance, Rodgers & Romani, 2005; Norris & Trudelle-Jackson, 2011). Adductor magnus MVIC testing were conducted while the participant was lying on their non-dominant side and their body extended (i.e., lower extremity and spine straight). Pressure was applied above the knee (i.e., against the medial aspect of the distal end of the thigh in the direction of abduction) (Kendall et al., 2005). Biceps femoris MVIC required the participant to lay prone in a neutral position, with the tibia in neutral and the knee flexed to 90 degrees. Hip extension was manually resisted (Kendall et al., 2005). Rectus femoris MVIC test was performed with the participant sitting at the edge of the table and the knee flexed 90 degrees. Knee extension was manually resisted by applying pressure to the lower tibia towards the table (Kendall et al., 2005). Lastly, gastrocnemius MVIC was performed with the participant seated at the edge of the table with the knee flexed at 90 degrees. Plantar flexion was manually resisted by the investigator (Kendall et al., 2005).

Following sEMG electrode placement and MMTs, eight retro-reflective markers were attached to the participants’ bony landmarks (dominant side): lateral malleolus, patella, lateral femoral condyle, greater trochanter, anterior superior iliac spine (ASIS), and clavicle (acromioclavicular joint), with an additional two markers on the contralateral ASIS and calcaneous (see Appendix F).

Once all retro-reflective markers were attached, and all the aforementioned procedures were performed, the participants were instructed to perform the assigned dynamic balance test, either the SEBT or the LqYBT. Participants performed three practice trials for each test. The number of trials was chosen to minimize the influence of a learning effect (Hertel & Denegar, 2010; Robinson & Gribble, 2008). After the practice trials, a two-minute rest period was given. For each test, participants were instructed to perform three maximum reaches, in each reach direction. To reduce fatigue, participants were given 10 seconds rest between each direction trial (Hertel et al., 2015).

For the LqYBT, the participants were instructed on the proper procedure for performing this test. The participants were coached to place their hands slightly above their hips in order to avoid the markers, stand on the base footplate block of the LqYBT, and align the toes of their stance leg at the positioning line. While maintaining single leg stance on the dominant leg, the participant was instructed to reach with the opposite leg in three directions (anterior, posteromedial and posterolateral). The anterior direction required the participant to reach as far as possible while pushing the anterior reaching indicator. Preforming the posteromedial direction required the participant to reach in the posterior medial direction as far as possible while pushing the posteromedial reaching indicator along the track. During the posterolateral reach, the participant was asked to reach as far back as possible while pushing the posterolateral reaching indicator along the track.

As the participant reached in the three directions, they were encouraged to push the indicator box as far as possible in all three tested directions. Attempts were excluded and repeated if the participant in either reach direction: (a) failed to maintain single-leg stance on the center platform, (b) failed to maintain hands in their designated position, (c) failed to keep the stance leg heel in contact with the base footplate block, (d) allowed their reach foot to touch the ground anywhere while reaching in the test direction, (e) allowed their reach foot to lose contact with the reach indicator any time during the trial or if they stepped over it for support, and (f) if they failed to recover to the start position after maximum reach distance achieved.

For the SEBT, the participant was coached to stand in the middle of the custom built SEBT pattern, position hands slightly above the hips, to avoid contact with the markers, and then perform three maximum single-leg reaches in three directions (i.e., anterior, posterolateral, and posteromedial). Participants were required to start from a double stance position, and balance on the dominant leg. Next, participants were asked to reach as far as possible in each of the three directions, and at the farthest possible reaching distance, the participant and was asked to make a light touch with the most distal part of the foot, and return to the start position (Robinson & Gribble 2008). Anterior direction required the participant to reach as far as possible along the anterior line and make a light touch on the line and return back to the start position. While performing in the posteromedial direction, the participant reached as far as possible along the posteromedial line, made a light touch on the line, and then returned to the starting position. Posterolateral direction required the participant to reach as far as possible along the posterolateral line and make a light touch on the line and turn back to the start position. Attempts were excluded and repeated if the participant: (a) failed to maintain the single-leg stance, and/or failed to keep stance leg heel in contact with the ground, b) did not keep their hands in position, (c) if their reach leg side foot touched the ground for support at any time while reaching, and (d) if they failed to recover back to the start position after reaching maximum distance achieved.

Data Analysis

For all trials of the two dynamic balance tests, sEMG data were recorded from the start of the movement the furthest reach point (Norris & Trudelle-Jachson,2011). The forward reaching phase began when the reaching leg moved in the assigned direction. The end of the phase was indicated at the point of maximum reach. For analysis the rectified sEMG was averaged over the phase defined as the start of movement to the end reach point. The average RMSE of the sEMG was normalized to the average MVIC recorded during the manual muscle test. Moreover, the tested muscles were grouped depending on their stabilization function of the joint. Two muscle stabilization groups were created, Hip stabilizer muscle group included gluteus medius and adductor magnus, and knee stabilizer muscle group included rectus femoris, biceps femoris and gastrocnemius. The activation of each grouped muscles were compered between the two balance tests.

The maximum reach distance in each direction of the SEBT and the LqYBT were normalized to the subject's dominant leg (stance leg) length. This was conducted by dividing the reach distance by the dominant leg length and then multiplied by 100 (Gribble & Hertel, 2003). The mean value of the normalized reach of the SEBT and the LqYBT across the three test trials in each direction were calculated for data analysis.

Lower extremity joint kinematics obtained at the point of maximum reach distance in the assigned test direction, by digital images (videos) were analyzed using Dartfish software (version 20.0; SPSS Inc., Chicago, IL, USA). Lower extremity joint kinematics of interest were the dominate side (stance leg) hip flexion, hip abduction/adduction, knee flexion, and knee abduction/abduction. Hip abduction/adduction was defined as the angle formed between the bilateral ASIS and the patella (Maykut et al., 2015). Hip flexion was defined as the angle formed between the stance leg ASIS and lateral femoral condyle. Knee flexion was defined as the angle formed by the lateral femoral epicondyle and the lateral malleolus markers (Norris & Olson 2011), and knee abduction/adduction was defined as the angle formed between the line that connects the marker of the stance leg ASIS, and the patella marker, and a second line that connects the marker of the patella and the frontal marker of the lateral malleolus (Stickler et al., 2015; Dingenen et al., 2015). Hip and knee adduction abduction range of motions will be calculated as absolute values.

The point of maximal reach in any direction of the SEBT was indicated at the farthest distance where the participant touched the floor. For data analysis, the mean values of angular displacement of the hip and the knee across three test trials were used. The point of maximal reach in any direction of the LqYBT was determined as the furthest distance at which the indicator block was placed. For data analysis, the mean values of angular displacement of the hip and the knee across three test trials were used (Kang, Kim, Kwon, Weon, Oh, & An, 2015).

Descriptive statistics for the normalized sEMG, and the normalized reach distance in each direction, in addition to the kinematics of the hip and knee of the dominant leg during the SEBT and the LqYBT will be calculated. All data were screened for assumption of normality using the Kolmogorov-Smirnov test. The Pearson product-moment correlation coefficient were used to determine the correlation between normalized reach in each direction and the kinematics of the hip and knee and pROM of the hip flexion, hip extension, hip abduction, hip adduction, and knee flexion.

The independent variables of this study were balance tests with two levels (SEBT, LqYBT), and sex with two levels (males, females), the dependent variable was the normalized average muscle activation amplitudes of the tested muscles.

A series of Mixed-Design ANOVAs were conducted to indicate the differences in the averaged normalized activation amplitudes of the selected stance leg muscles. The five tested muscles were gluteus medius, adductor magnus, rectus femoris, biceps femoris, and gastrocnemius. The activation amplitudes of the selected muscle were obtained for each reaching direction of the SEBT and LqYBT. In addition two Mixed-Design ANOVAs were conducted to indicate the differences in the grouped averaged normalized activation of the stance leg hip stabilizer muscle group and knee stabilizer muscle group.

A series of multiple regression analysis was conducted to determine which independent variables (hip flexion angle, adduction/abduction, knee flexion, and knee adduction/abduction) predicted the each reaching distance of the balance tests.

Additional multiple regressions analyses were conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted each reaching distance of the balance tests. All statistical analyses were performed using SPSS software (version 20.0; SPSS Inc., Chicago, IL, USA), with an alpha level set a priori at $p \leq 0.05$, will be utilized.

Chapter IV: Results

The purpose of this study was to compare the lower extremity kinematics and muscle activation amplitudes between the Star Excursion Balance (SEBT) and the Lower quarter Y-Balance Test (LqYBT), of recreationally active college participants. This research examined the differences in the performance on these tests through the kinematics of: a) hip flexion, hip abduction/adduction b) knee flexion, knee abduction /adduction, and c) the activation amplitudes of the gluteus medius, adductor magnus, hamstring, rectus femoris and the gastrocnemius musculature of the stance leg. This chapter presents the statistical results of the collected data on the stance leg during the forward phase of the selected reaching directions of the two balance tests. Whereas each session will represent the kinematics and muscle activation amplitudes of the stance leg in one of the three reaching directions of both balance test directions: a) anterior, b) posteromedial, and c) posterolateral.

Participant Demographics

Twenty-six recreationally active (15 females and 11 males) Auburn University students participated in this research study. All participants were healthy and free of injuries within 6 months of the conducted date of this research study. A summary of the participant demographics is presented in Table 1.

Table 1. Participants demographics

	Sex			
	Male (*N* = 11)		Female (*N* = 15)	
	Mean	*SD*	*Mean*	*SD*
Age (years)	21.70	2.28	21.53	1.40
Mass (kg)	75.45	3.35	57.80	9.45
Height (cm)	176.68	5.33	164.12	6.62
Leg length (cm)	93.09	3.70	88.23	4.26

Anterior Reaching Direction

The following results address the first two research questions related to the anterior reaching direction:

- To what extent are there differences in muscle activation amplitudes between SEBT and the LqYBT in all three tested directions? Are there any differences between males and females?
- To what extent are there differences in hip and knee joint kinematics between SEBT and the LqYBT in all three tested directions? Are there any differences between males and females?

The independent variables of this study were balance tests with two levels (SEBT, LqYBT), and sex with two levels (males, females). The dependent variables were the normalized average muscle activation amplitudes of the tested muscles. A series of Mixed-Design ANOVAs were conducted to indicate the differences in the averaged normalized activation amplitudes of the selected stance leg muscles. A post hoc paired *t*-test with Bonferroni adjustment was performed if any overall significant results were obtained for the normalized sEMG and the kinematic data. The effect size (partial eta-squared, denoted as partial η2) were also reported. The strength of the effect sizes was evaluated using guidelines described by Cohen (1992), weak < .2, moderate range 0.21 - 0.79, and strong > 0.8. The five tested muscles were gluteus medius, adductor magnus, rectus femoris, biceps femoris, and gastrocnemius. The activation amplitudes of the selected muscles were obtained during the forward phase of the anterior reaching direction of the SEBT and LqYBT. Two repeated measures ANOVAs were conducted to assess the differences in the averaged normalized amplitudes, when muscles were combined as two units according to their role, hip stabilizers (gluteus medius, adductor magnus), and knee stabilizers (rectus femoris, biceps femoris, and gastrocnemius) (See Figure1).

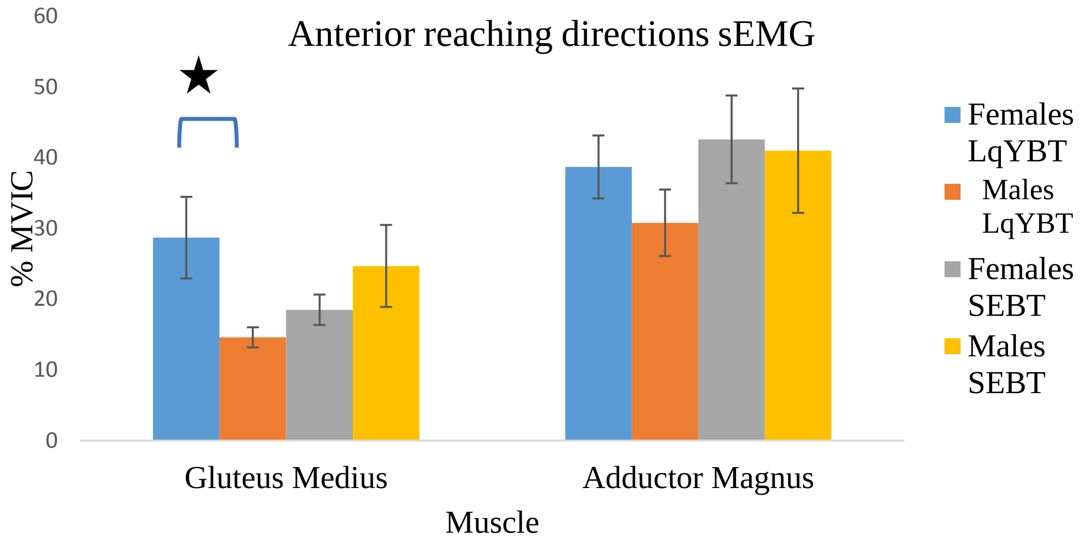

Figure 1. Anterior reaching direction peak normalized EMG amplitudes expressed as % MVIC, for female and male participants for the lower quarter Y-Balance Test (LqYBT) and the Star

★

Excursion Balance Test (SEBT). Denotes a significant difference between the means of the indicated means of each muscle at the $p \leq 0.01$ level.

Gluteus Medius

Differences in gluteus medius muscle activation during the forward phase of the anterior reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that neither balance test, *F*(1,24) = .038, *p* = .847, partial η^2 = .002, nor sex, *F*(1,24) = 1.726, *p* = .201, partial η^2 = .067, had a statistically significant influence on the activation of the gluteus medius muscle. However, the interaction between the two factors was statistically significant, *F*(1,24) = 4.615, *p* = .042, partial η^2 = .161. Post-hoc paired sample *t* tests revealed a significant difference in the activation of the gluteus medius between males and females participants while performing the LqYBT. Female participants showed higher averaged normalized activation of the gluteus medius muscle (*M* = 28.622, *SD* =23.14), than male participants (*M* = 14.576, *SD* =5.67) while performing the anterior reach of the LqYBT (see Figure 1).

Adductor Magnus

Differences in adductor magnus muscle activation during the forward phase of the anterior reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that neither balance test, *F*(1,24) = 1.303, *p* = .265, partial η^2 = .051, nor sex, *F*(1,24) = .395, *p* = .535, partial η^2 = .016, had a statistically significant effect on the activation of the adductor magnus muscle. Also, the interaction between the two factors was statistically non-significant, *F*(1,24) = .266, *p* = .611, partial η^2 = .011 (see Figure 1).

Hip Muscle Group

A two-way repeated measures ANOVA with between-subjects factors of sex (females, males) and balance test (SEBT, LqYBT) was conducted on the combined muscle activity of the gluteus medius and the adductor magnus muscle, as the hip stabilizer group. Recorded during the forward phase of the anterior reaching direction of the two balance tests, the results indicated that neither balance tests, *F*(1,24) = 1.288, *p* = .268, partial η^2 = .051, nor sex, *F*(1,24) = .411, *p* = .528, partial η^2 = .017, had a significant effect on the activation of the tested hip stabilizers muscle group. Also, the interaction between the two factors was not significant, *F*(1,24) = .597, *p* = .543, partial η^2 = .012 (see Figure 2).

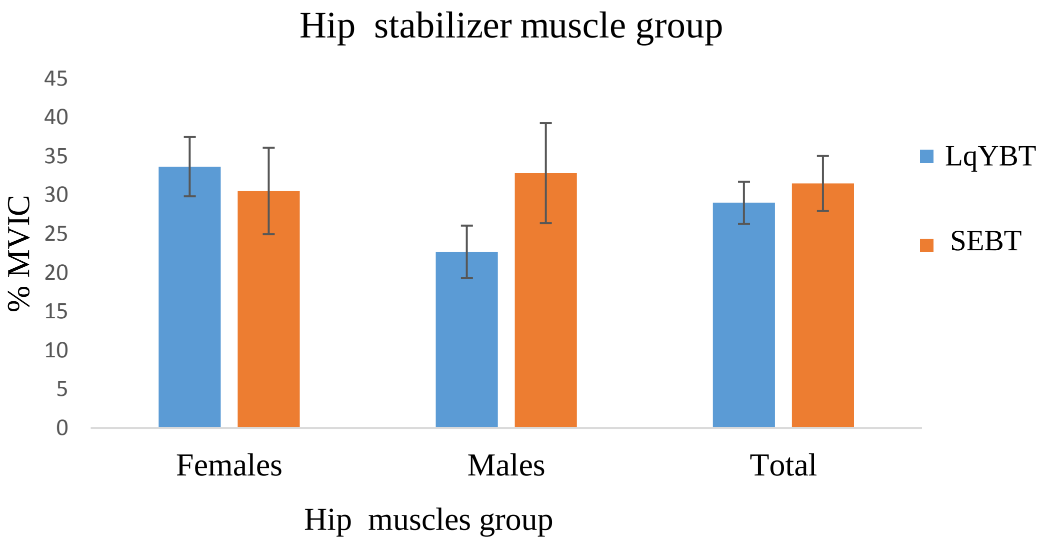

Figure 2. Anterior reaching direction peak normalized EMG amplitudes of the hip muscle group expressed as % MVIC for the female and male participants.

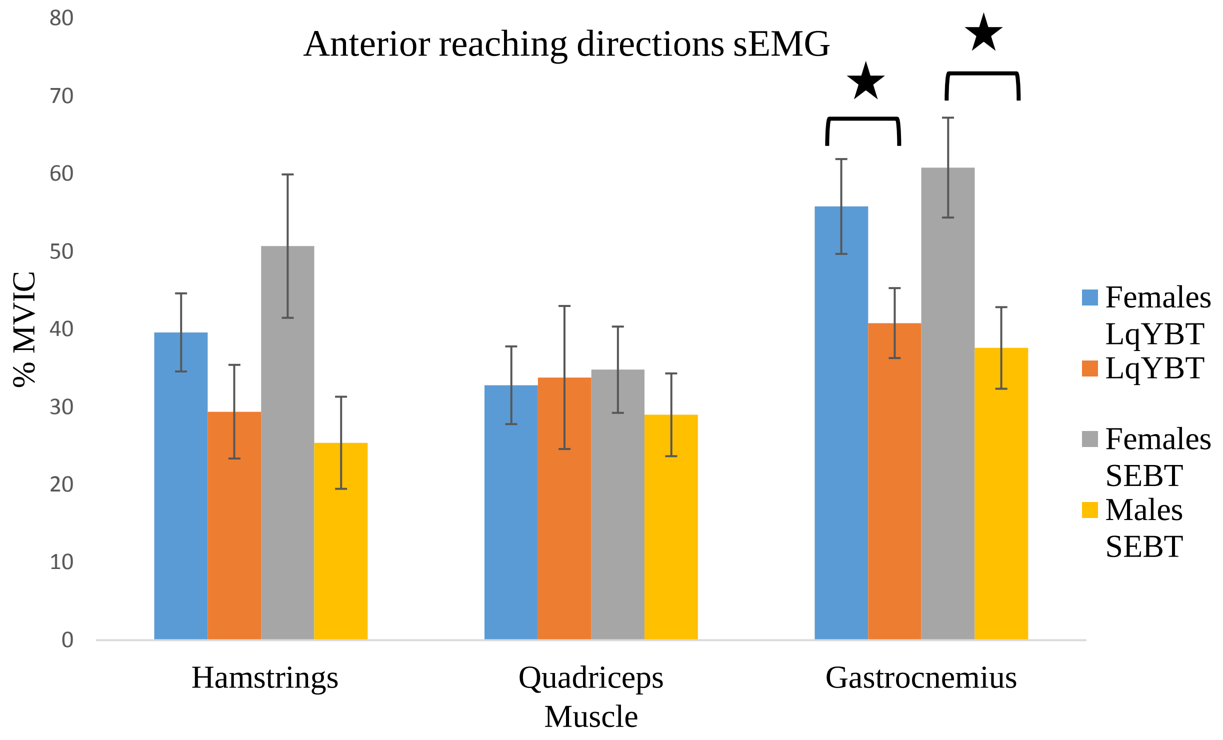

Figure 3. Anterior reaching direction peak normalized EMG amplitudes expressed as % MVIC, for female and male participants for the lower quarter Y-Balance Test (LqYBT) and the Star Excursion Balance Test (SEBT). ★ Denotes a significant difference between the means of the indicated means of each muscle at the $p \leq 0.05$ level.

Biceps Femoris

Differences in the biceps femoris activation during the forward phase of the anterior reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT) and a between-subjects factor of sex (females, males). The results showed that neither balance test, $F(1,24) = .054$, $p = .818$, partial $\eta^2 = .002$, nor sex, $F(1,24) = 1.094$, $p = .201$, partial $\eta^2 = .067$, had a statistically significant effect on the activation of the biceps femoris. Also, the interaction between the two factors was not statistically significant, $F(1,24) = .125$, $p = .726$, partial $\eta^2 = .005$ (see Figure 3).

Rectus Femoris

Differences in rectus femoris activation during the forward phase of the anterior reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that neither balance test, $F(1,24) = .472$, $p =.498$, partial $\eta^2 = .019$, nor sex, $F(1,24) = 1.462$, $p =.238$, partial $\eta^2 = .057$, had a statistically significant effect on the activation of the rectus femoris. Also, the interaction between the two factors was not statistically significant, $F(1,24) = 3.746$, $p = .065$, partial $\eta^2 = .135$ (see Figure 3).

Gastrocnemius

Differences in the gastrocnemius muscles activation during the forward phase of the anterior reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that sex had a significant effect on the activation of the gastrocnemius muscles, $F(1,24) = 6.371$, $p =.019$, and presented with a small effect size partial $\eta^2 = .210$. Whereas female participants had a higher average muscle activation amplitude than male participants in both tests. However, the interaction between balance tests and participants sex was non-significant, $F(1,24) = .029$, $p =.866$, partial $\eta^2 = .001$, and $F(1,24) = .658$, $p =.425$, partial $\eta^2 = .027$, respectively (see Figure 3).

Knee Stabilizer Muscle Group

A two-way repeated measures ANOVA with between-subjects factors of sex (females, males) and balance test (SEBT, LqYBT) was conducted on the combined averaged activation of the knee stabilizer muscle group (rectus femoris, hamstring, and gastrocnemius), during the forward phase of the anterior reaching direction of the two balance tests. The results revealed that balance test type did not affect the average activation of the knee muscle group, *F*(1,24) = .059, *p* = .809, partial η^2 = .002. The participants sex did significantly affect the activation of the tested knee stabilizers muscle group, *F*(1,24) = 6.828, *p* = .015, with a moderate effect size partial η^2 = .221. Female participants had a higher average muscle activation group than male participants. Although, the interaction between the two factors was non-significant, *F*(1,24) = .1.578, *p* = .221, partial η^2 = .062 (see Figure 4).

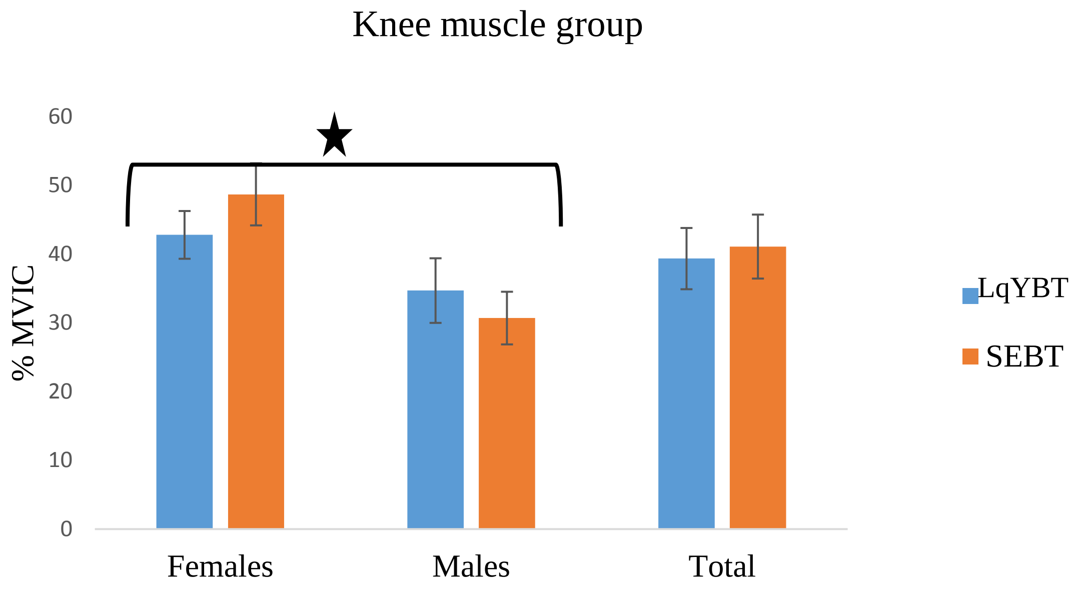

Figure 4. Anterior reaching direction Knee muscle group peak normalized EMG amplitudes expressed as % MVIC. ★ Denotes a significant difference between the means of the indicated means of each muscle at the *p* ≤0.05 level.

Kinematics of the Anterior Reaching Direction of the Balance Tests

Kinematic data of the stance leg hip and the knee joints were obtained at the point where the participant reached the farthest in the anterior direction of the two balance tests. The SEBT farthest reaching distance point was indicated as the point of the initial ground touch of the reaching leg. The LqYBT farthest reaching distance point was indicated as the point of the where the participant stopped sliding the LqYBT block any farther with the reaching leg. Descriptive statistics for these analyses are presented in Table 2.

Table 2.

Anterior balance tests reaching direction kinematics (°)

Variable	LqYBT			SEBT		
	Females	Males	Total	Females	Males	Total
	M SD	*M SD*	*M SD*	*M SD*	*M SD*	*M SD*
Hip flexion (°)	60.1±8	62.46±7.1	61.1±7.6	63.6±4.7	59.7±6.2	62±5.6
Hip Abd/Add (°)	13.94±5.5	14.71±3.1	14.27±4.6	12.72±5.7	9.84±2.6	11.5±4.8
Knee flexion (°)	110.9±11.3	117.1±11.6	113.6±11.6	112.4±14	116.6±10.7	114.2±12.7
Knee Abd/Add (°)	12.4±5.8	10±4.8	11.4±5.4	11.5±5.6	5.8±3	9.1±5.4

Note. Female (*N* = 15), males (*N* = 11). Abduction/Adduction (Abd/Add) is presented as absolute angles. All angles are presented in degrees (°). Higher flexion angles represent anatomically less flexion of the joint.

Hip Flexion

Differences in the hip flexion angle at the point of the farthest anterior reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females,

males). The results revealed that neither the type of the balance test, *F*(1,24) = .0.091, *p* =.765, partial η^2 = .004, nor the performance between sex, *F*(1,24) = 0.107, *p* =.747, partial η^2 = .004, significantly differed in hip flexion However, the interaction between the two factors was statistically significantly different, *F*(1,24) = 5.063, *p* = .034, wtih a small effect size partial η^2 = .174. Post hoc paired-samples *t* test was conducted to examine the significant interaction, and revealed a significant difference between females and male's hip flexion while performing the SEBT. Regarding the means of the averaged acute hip flexion, female participants had ahigher anatomical averaged hip flexion (*M* = 28.28°, *SD* = 4.52°) when performing the anterior reach of the SEBT when compared to the male participants (*M* = 27.66, *SD* = 7.8°). Descriptive statistics for these analyses are presented in Table 2.

Hip Abduction/adduction

Differences in the hip abduction/adduction range of motion at the point of the farthest anterior reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT) and a between-subjects factor of sex (females, males). The hip abduction/adduction range of motion was significantly different between the two balance tests, *F*(1,24) = 18.075, *p* < .001, partial η^2 = .430, such that participants had a higher averaged hip abduction/adduction range of motion when they performed the LqYBT compared to the SEBT. There was no significant difference in hip abduction/adduction range of motion between males and females, *F*(1,24) = .146, *p* =.706, partial η^2 = .006. However, the interaction between the two factors was statistically significant, *F(*1,24) = 6.736, *p* = .016, partial η^2 = .219. Regarding the averaged means, female participants had a higher averaged hip abduction/adduction range of motion when they performed the anterior reach of the SEBT compared to the male participants; whereas, males had a higher hip abduction/adduction range of motion when they performed the anterior reach of the LqYBT, when compared to the females. Descriptive statistics for these analyses are presented in Table 2.

Knee Flexion

Differences in the knee flexion at the point of the farthest anterior reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subject factor of sex (females, males). The results revealed that neither the type of the balance test $F(1,24) = .059$, $p =.811$, partial $\eta^2 =.002$, nor the performance between sexes, $F(1,24) = 1.405$, $p =.247$, partial $\eta^2 = .055$, significantly differed in knee flexion. Also, the interaction between the two factors was not statistically significant, $F(1,24) = .275$, $p = .605$, partial $\eta^2 = .011$. Descriptive statistics for these analyses are presented in Table 2.

Knee Abduction/Adduction

Differences in the knee abduction/adduction range of motion at the point of the farthest posteromedial reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT), and a between-subjects factor of sex (females, males). Knee abduction/adduction range of motion was not significantly different between the two balance tests $F(1,24) = 3.599$, $p =.070$, partial $\eta^2 = .130$. There was a significant difference between females and males knee abduction/adduction range of motion, $F(1,24) = 7.300$, $p =.773$, partial $\eta^2 = .233$. Female participants performed the balance tests with a higher knee abduction/adduction range of motion in both balance tests. The interaction between balance test and sex was not significant, $F(1,24) = 1.527$, $p = .070$, partial $\eta^2 = .130$, suggesting that female and male participant’s knee abduction/adduction range of motion did not differ between the two balance tests. Descriptive statistics for these analyses are presented in Table 2.

Posteromedial Reaching Direction

The following results address the research questions in the posteromedial reaching direction:

- To what extent are there differences in muscles activation amplitudes between SEBT and the LqYBT in the in all three tested directions? Are there any differences between males and females?
- To what extent are there differences in hip and knee joint kinematics between SEBT and the LqYBT in all three tested directions? Are there any differences between males and females?

The independent variables of this study were balance tests with two levels (SEBT, LqYBT), and sex with two levels (males, females). The dependent variable was the normalized average activation amplitudes of the tested muscles. A series of mixed-design ANOVAs were conducted to indicate the differences in the averaged normalized activation amplitudes of the selected stance leg muscles, and the kinematic of the hip and the knee. A post hoc paired *t*-test with Bonferroni adjustment was performed if any overall significant results were obtained for the normalized sEMG and the kinematic data. The effect size (partial eta-squared, denoted as partial η2) was also reported. The strength of the effect sizes was evaluated using guidelines described by Cohen (1992.), weak < .2, moderate range 0.21 - 0.79, and strong > .8

The five tested muscles were gluteus medius, adductor magnus, rectus femoris, biceps femoris, and gastrocnemius. The activation amplitudes of the selected muscle were obtained during the forward phase of the posteromedial reaching direction of the SEBT and LqYBT. Two repeated measures ANOVAs were conducted to assess the differences in the averaged normalized amplitudes, furthermore, muscles were combined as two units according to their role. These two units included: hip stabilizers (gluteus medius, adductor magnus), and knee stabilizers (rectus femoris, biceps femoris, and gastrocnemius).

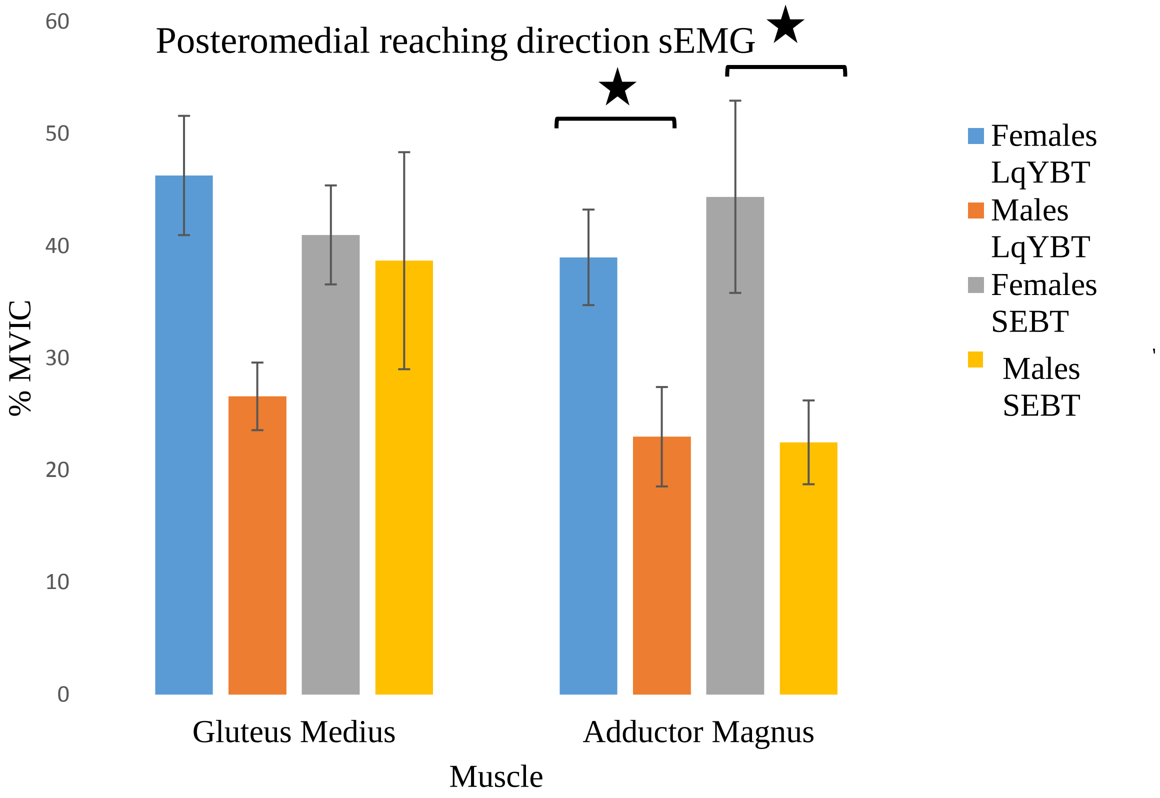

Figure 5. Posteromedial reaching direction peak normalized EMG amplitudes expressed as % MVIC for female and male participants. ★ Denotes significant differences at $p \leq 0.05$.

Gluteus Medius

Differences in the gluteus medius muscle activation during the forward phase of the posteromedial reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females,

males). The results showed that neither balance test type, $F(1,24) = .434$, $p > 0.05$, partial $\eta^2 = .018$, nor sex, $F(1,24) = 2.75$, $p > 0.05$, partial $\eta^2 = .103$, had a statistically significant effect on the activation amplitude of the gluteus medius muscle. Also, the interaction between the two factors was statistically non-significant, $F(1,24) = 2.936$, $p > 0.05$, partial $\eta^2 = .109$. (see Figure 5).

Adductor Magnus

Differences in the adductor magnus muscle activation during the forward phase of the posteromedial reaching direction were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subject factor of sex (females, males). The results showed that sex had a significant effect on the activation of the adductor magnus, $F(1,24) = .7.337$, $p =.012$, partial $\eta^2 =.234$. Female participants had higher muscle activation amplitude than male participants for both tests. However, balance test and the interaction between the two factors were non-significant, $F(1,24) = .010$, $p > 0.05$, partial $\eta^2 = .00$ and $F(1,24) = .002$, $p >0.05$, partial $\eta^2 = .00$ (see Figure 5).

Hip Muscle Group

A two-way repeated measures ANOVA with between subjects factors of 2 sex (females, males) x 2 balance test (SEBT, LqYBT) was conducted on the combined muscle activity of the gluteus medius and the adductor magnus muscle, as the hip stabilizer group. During the forward phase of the posteromedial reaching direction of the two balance tests, neither balance tests, $F(1,24) = 2.496$, $p > 0.05$, partial $\eta^2 = .094$, nor sex, $F(1,24) = 2.572$, $p >0.05$, partial $\eta^2 = .097$, had a statistically significant effect on the activation of the tested hip stabilizers muscle group.

Also, the interaction between the two factors was non-significant, *F*(1,24) = 1.464, $p > 0.05$, partial $\eta^2 = .058$ (see Figure 6).

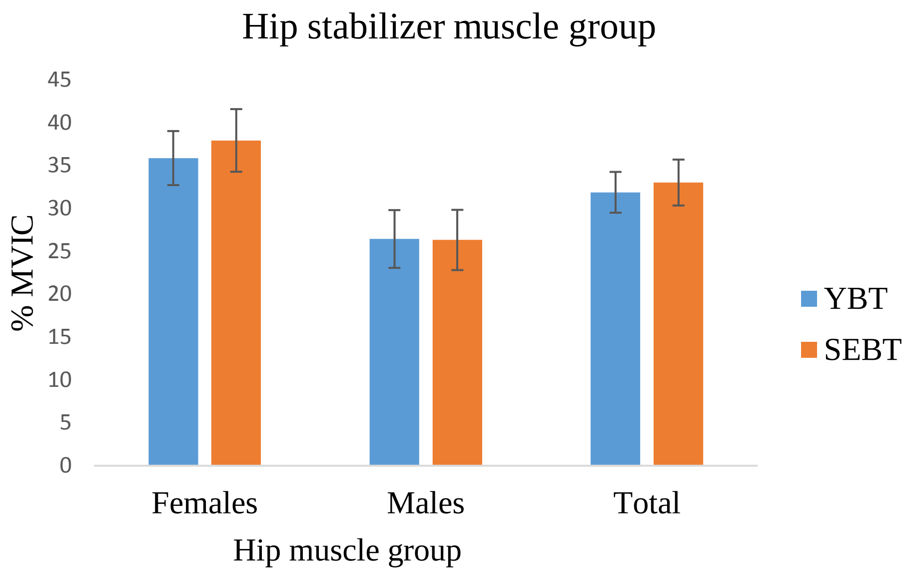

Figure 6. Posteromedial reaching direction peak normalized EMG amplitudes of the hip muscle group expressed as % MVIC.

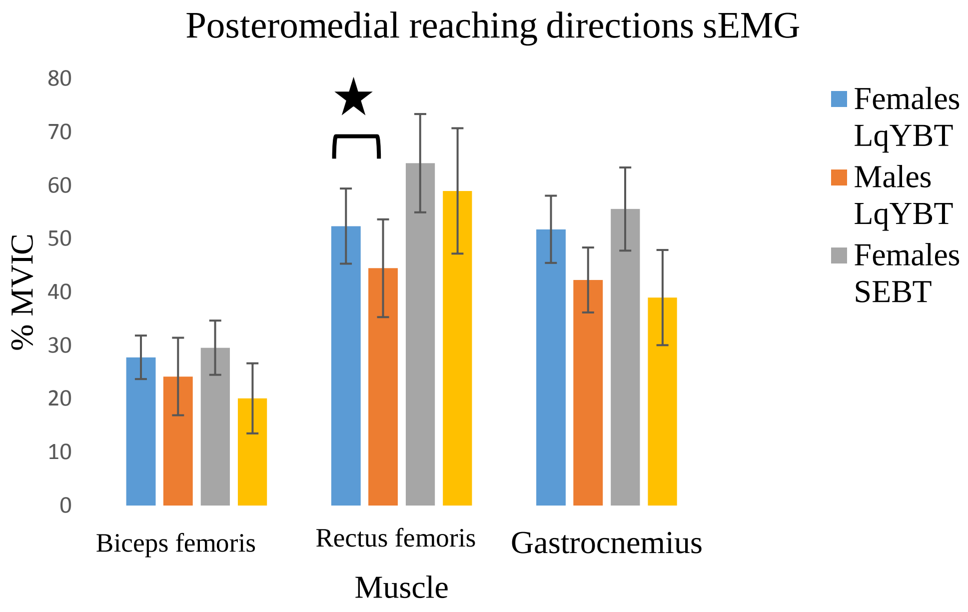

Figure 7. Posteromedial reaching direction peak normalized EMG amplitudes expressed as % MVIC for female and male participants. ★ Denotes a significant difference between the indicated means at *p*<0.056.

Biceps Femoris

Hamstring muscle activation differences recorded during the forward phase of the posteromedial reaching direction were investigated by conducting a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that neither balance test, *F*(1,24) =.177, *p* =.678, partial η^2 = .007, nor sex, *F*(1,24) = 1.731, *p* =.306, partial η^2 = .044, had a statistically significant effect on the activation of the biceps femoris muscles. Also, the interaction between the two factors was not statistically significant, *F*(1,24) = .356, *p* = .556, partial η^2 = .015 (see Figure 7).

Rectus Femoris

Rectus femoris muscle activation differences, recorded during the forward phase of the posteromedial reaching direction, were investigated by conducting a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that balance tests had a significant effect on the activation of the rectus femoris, *F*(1,24) = .4.697, *p* =.040, partial η^2 = .164, specifically, the average activation of the rectus femoris was higher during the performance of the SEBT than the LqYBT. Sex and the interaction between the two factors were non-significant, *F*(1,24) = .310, *p* =.583, partial η^2 = .013, and *F*(1,24) = .049, *p* =827, partial η^2 = .002, respectively (see Figure 7).

Gastrocnemius

Gastrocnemius muscle activation differences recorded during the forward phase of the posteromedial reaching direction were investigated by conducting a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that neither balance test, $F(1,24) = .002$, $p = .968$, partial $\eta^2 = .00$, nor sex, $F(1,24) = 2.312$, $p = .141$, partial $\eta^2 = .088$, had a statistically significant effect on the activation of the gastrocnemius muscle. Also, the interaction between the two factors was not statistically significant, $F(1,24) = .330$, $p = .571$, partial $\eta^2 = .014$ (see Figure 7).

Knee Stabilizer Muscle Group

A two-way repeated measures ANOVA with between-subjects factor of 2 sex (females, males) x 2 balance test (SEBT, LqYBT) was conducted on the combined averaged activation of knee stabilizer muscle group (rectus femoris, hamstring, and gastrocnemius), during the forward phase of the posteromedial reaching direction of the two balance tests. Neither balance test, $F(1,24) = 1.025$, $p = .321$, partial $\eta^2 = .041$, nor sex, $F(1,24) = 2.360$, $p = .138$, partial $\eta^2 = .090$, had a statistically significant effect on the activation of the tested knee stabilizers muscle group. Also, the interaction between the two factors was non-significant, $F(1,24) = .180$, $p = .675$, partial $\eta^2 = .007$ (see Figure 8).

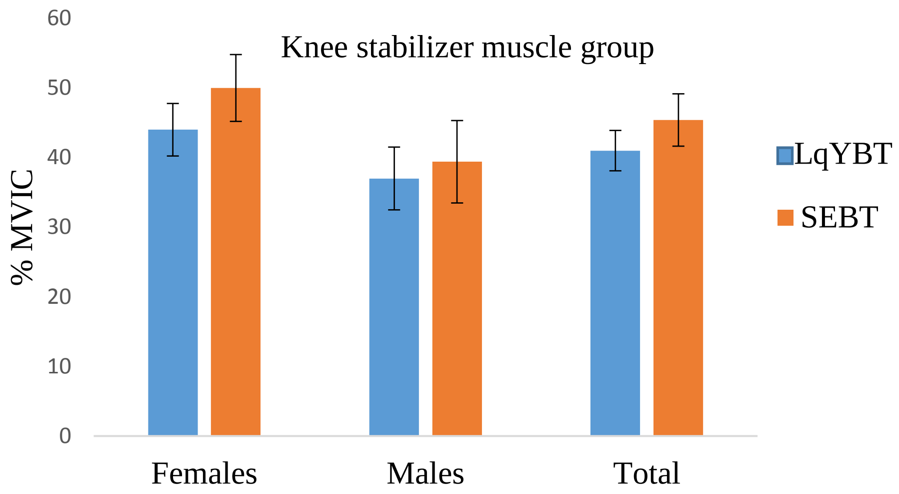

Figure 8. Posteromedial reaching direction peak normalized EMG amplitudes of the knee muscle group expressed as % MVIC.

Kinematics of the Posteromedial Reaching Direction of the Balance Tests

Kinematic data of the stance leg hip and the knee joints were obtained at the point where the participant reached the farthest in the posteromedial direction of the two balance tests. The SEBT farthest reaching distance point was indicated as the point of the initial ground touch of the reaching leg. The LqYBT farthest reaching distance point was indicated as the point where the participant stopped sliding the LqYBT block any farther, with the reaching leg. Descriptive statistics for these analyses are presented in Table 3.

Table 3.

Posteromedial balance tests reaching direction kinematics

Variable	LqYBT			SEBT		
	Females	Males	Total	Females	Males	Total
	M SD	*M SD*	*M SD*	*M SD*	*M SD*	*M SD*
Hip Flexion (°)	60.1±8	62.46±7.1	61.1±7.6	63.6±4.7	59.7±6.2	62±5.6
Hip Abd/Add (°)	17.6±8.20	17±7.30	17.3±7.70	14.3±10.8	11.8±7.71	13.3±9.50
Knee flexion (°)	118.7±120	117.3±10	118.1±11	122±7.6	118.5±9.2	120.5±8.30
Knee Abd/Add (°)	18.8±9.20	19.1±7.40	19±8.30	15.1±8.7	11.5±4.81	13.6±7.4

Note: Female (N= 15), males (N= 11). Abduction/Adduction (Abd/Add) are presented as absolute angles. All angles are presented in degrees (°).

Hip Flexion

Differences in the hip flexion angle at the point of the farthest posteromedial reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed a significant difference in hip flexion between the two balance tests, $F(1,24) = 13.735$, $p = .001$, partial $\eta^2 = .364$. Participants had a higher average hip flexion angle when preformed SEBT than they did performing the LqYBT. The results also showed significant hip flexion differences between males and females, $F(1,24) = 4.323$, $p = .048$, partial $\eta^2 = .153$, such that female participants had a higher average hip flexion than male participants in both tests. However, the interaction between the two factors was not statistically significant, $F(1,24) = 1.909$, $p = .180$, partial $\eta^2 = .074$. Descriptive statistics for these analyses are presented in Table 3.

Hip Abduction/adduction

Differences in the hip abduction/adduction range of motions at the point of the farthest posteromedial reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT) and a between-subjects factor of sex (females, males). The hip abduction/adduction range of motion was significantly different between the two balance tests, $F(1,24) = 6.743$, $p =.016$, partial $\eta^2 = .219$. Participants had a higher averaged hip abduction/adduction range of motion while performing the LqYBT compared to the SEBT. However, neither the main effect of sex, $F(1,24) = .269$, $p =.609$, partial $\eta^2 = .011$, nor the interaction between the two factors were statistically significant, $F(1,24) = .335$, $p = .568$, partial $\eta^2 = .219$. Descriptive statistics for these analyses are presented in Table 3.

Knee Flexion

Differences in the knee flexion angle at the point of the farthest forward reaching distance in the postereomedial direction of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT) and a between-subjects factor of sex (females, males). The results indicated that knee flexion did not significantly differ between the balance tests, $F(1,24) = 1.368$, $p =.254$, partial $\eta^2 =.054$ nor sex, $F(1,24) = .536$, $p =.471$, partial $\eta^2 = .022$. Also, the interaction between the two factors was not statistically significant, $F(1,24) = .295$, $p = .592$, partial $\eta^2 = .012$. Descriptive statistics for these analyses are presented in Table 3.

Knee Abduction/Adduction

Differences in the knee abduction/adduction range of motion at the point of the farthest posteromedial reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT) and a between-subjects factor of sex (females, males). Results showed a significant difference in knee abduction/adduction range of motion between the SEBT and the YBT, $F(1,24) = 12.47$, $p =.002$, partial $\eta^2 = .342$. Participants' averaged knee abduction/adduction range of motion was higher during the performance of the LqYBT as compared to the performance of the SEBT. However, there was no significant difference between males and females, $F(1,24) = .364$, $p =.552$, partial $\eta^2 = .015$. Also, the interaction between balance test and sex was not significant, $F(1,24) = 1.521$, $p = .229$, partial $\eta^2 = .060$. Suggesting that females and males knee abduction/adduction range of motion did not differ between sexes during the performance of the two balance tests. Descriptive statistics for these analyses are presented in Table 3.

Posterolateral Reaching Direction

The following results address the posterolateral reaching direction:

- To what extent are there differences in muscles activation amplitudes between SEBT and the LqYBT in the in all three tested directions? Are there any differences between males and females?
- To what extent are there differences in hip and knee joint kinematics between SEBT and the LQYBT in all three tested directions? Are there any differences between males and females?

The independent variables of this study were balance tests with two levels (SEBT, LqYBT), and sex with two levels (males, females). The dependent variable was the normalized average activation amplitudes of the tested muscles. A series of mixed-design ANOVAs were conducted to indicate the differences in the averaged normalized activation amplitudes of the selected stance leg muscles. A post hoc paired *t*-test with Bonferroni adjustment was performed if any overall significant results were obtained for the normalized sEMG and the kinematic data. The effect size (partial eta-squared, denoted as partial η2) was also reported values. The strength of the effect sizes was evaluated using guidelines described by Cohen (1992.), weak < .2, moderate range 0.21 - 0.79, and strong > .8. The five tested muscles were the gluteus medius, adductor magnus, rectus femoris, biceps femoris, and gastrocnemius. The activation amplitudes of the selected muscle were obtained during the forward phase of the posterolateral reaching direction of the SEBT and LqYBT. Two repeated measures ANOVAs were also conducted to assess the differences in the averaged normalized amplitudes, where muscles were combined as two units according to their roll: hip stabilizers (gluteus medius, adductor magnus), and knee stabilizers (rectus femoris, biceps femoris, and gastrocnemius).

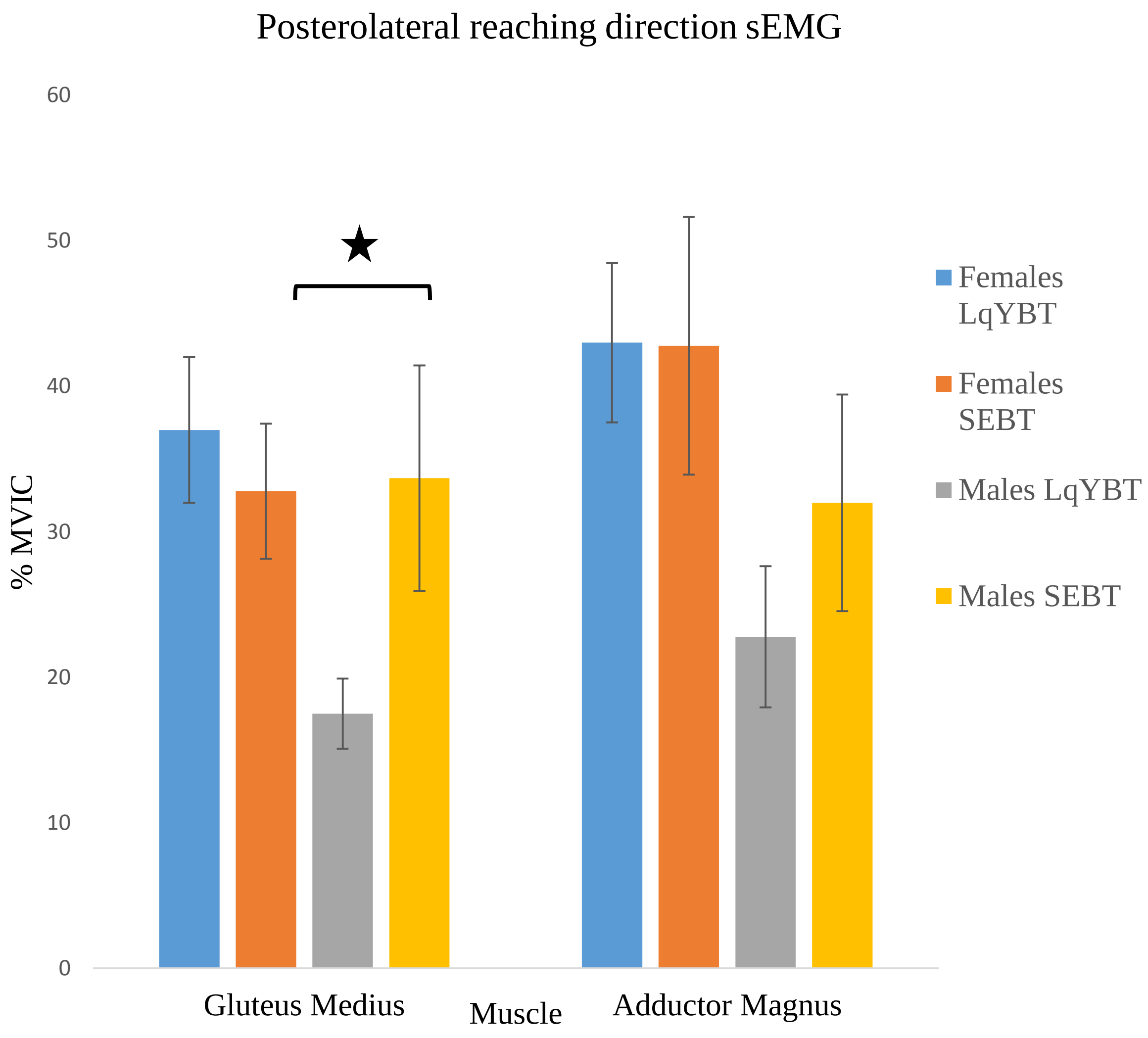

Figure 9. Posterolateral reaching direction peak normalized EMG amplitudes expressed as % MVIC. ★ Denotes a significant difference between the indicated means at $p < 0.05$.

Gluteus Medius

Gluteus medius muscle activation differences, recorded during the forward phase of the posterolateral reaching direction, were assessed by conducting a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results revealed a significant effect of sex, $F(1,24) = 5.438$, $p = .028$, partial $\eta^2 = .185$. The results revealed a non-significant effect of balance test, $F(1,24) = 2.789$, p

> 0.05, partial η2 = .104, on the activation of the gluteus medius muscle. However, the interaction between the two factors was statistically significant, $F(1,24) = 5.775$, $p = .024$, partial $\eta^2 = .194$. Post hoc pair sample *t* test indicated that female participants showed higher gluteus medius muscle activation than the male participants while performing the posterolateral reach direction of the LqYBT. The male participants had higher gluteus medius activation during the performance of the SEBT (see Figure 9).

Adductor Magnus

Adductor magnus muscle activation differences, recorded during the forward phase of the posterolateral reaching direction, were assessed by conducting a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results showed that neither sex, $F(1,24) = 3.499$, $p >0.05$, partial $\eta^2 = .127$, nor balance test, $F(1,24) = .638$, $p > 0.05$, partial $\eta^2 = .026$, had a statistically significant effect on the activation amplitude of the adductor magnus muscle. Also, the interaction between the two factors was non-significant, $F(1,24) = .691$, $p >0.05$, partial $\eta^2 = .028$ (see Figure 9).

Hip Stabilizer Muscle Group

A two-way repeated measures ANOVA with between subjects factors of sex (females, males) balance test (SEBT, LqYBT) was conducted on the combined muscle activity of the gluteus medius and the adductor magnus muscles, as a hip stabilizer. The muscle activation amplitudes were recorded during the forward phase of the posterolateral reaching direction of the two balance tests. Neither balance test, $F(1,24) = .638$, $p > 0.05$, partial $\eta^2 = .026$, nor sex, $F(1,24) = 3.499$, $p > 0.05$, partial $\eta^2 = .127$, had a statistically significant effect on the activation of the tested hip stabilizers muscle group. Also, the interaction between the two factors was non-significant, $F(1,24) = .691$, $p > 0.05$, partial $\eta^2 = .028$ (see Figure 10).

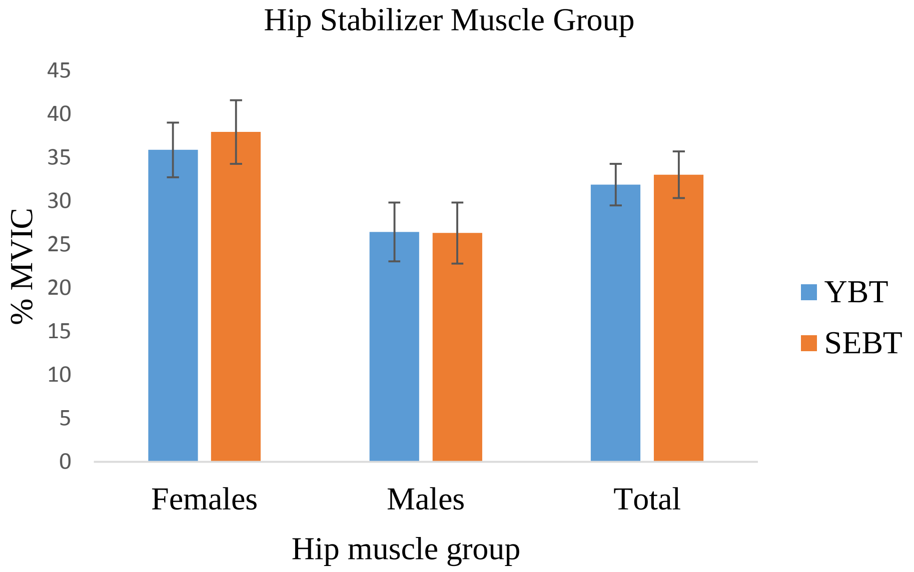

Figure 10. Posterolateral reaching direction peak normalized EMG amplitudes of the hip muscle group expressed as % MVIC.

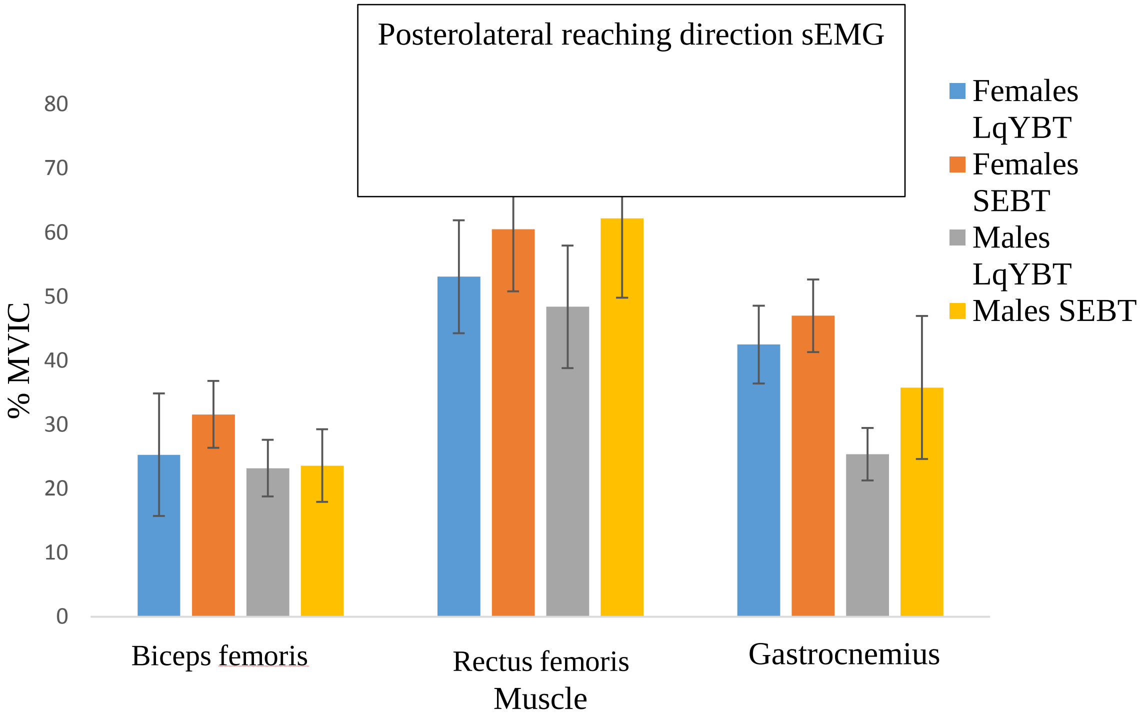

Figure 11. Posterolateral reaching direction peak normalized EMG amplitudes expressed as % MVIC.

Biceps Femoris

A mixed between and within subjects ANOVA was conducted to assess the effect of two different balance tests (SEBT and LqYBT) on participants' biceps femoris muscle activation during the forward phase of the posterolateral reaching direction and across sexes (males and females). The results showed that neither balance test, *F*(1,24) =.550 *p* =.466, partial η^2 =.022, nor sex, *F*(1,24) = 1.155, *p* =.293, partial η^2 = .046, produced a statistically significant difference in the activation of the biceps femoris muscles. Also, the interaction between the two factors was not statistically significant, *F*(1,24) = .422, *p* = .522, partial η^2 = .017 (Figure 11).

Rectus femoris

A mixed between and within subjects ANOVA was conducted to assess the effect of two different balance tests (SEBT and LqYBT) on participants' rectus femoris muscle activation amplitude during the forward phase of the posterolateral reaching direction and across sexes (males and females). The results showed that neither balance test, *F*(1,24) =2.651, *p* =.117, partial η^2 = .099, nor sex, *F*(1,24) = .014, *p* =.907, partial η^2 = .001, had a statistically significant effect on the activation amplitude of the rectus femoris. Also, the interaction between the two factors was not statistically significant, *F*(1,24) = .249, *p* = .623, partial η^2 = .010 (see Figure 11).

Gastrocnemius

A mixed between and within subjects ANOVA was conducted to assess the effect of two different balance tests (SEBT and LqYBT) on participants' gastrocnemius muscle activation during the forward phase of the posterolateral reaching direction and across sexes (males and females). The results showed that neither balance test, *F*(1,24) =1.284, *p* =.2.68, partial η^2 = .051, nor sex, *F*(1,24) = 3.645, *p* =.068, partial η^2 = .132, had a statistically significant effect on the activation amplitude of the gastrocnemius muscle. Also, the interaction between the two factors was not statistically significant, *F*(1,24) = .204, *p* = .655, partial η^2 = .008. Descriptive statistics for these analyses are presented in Figure 11.

Knee Stabilizer Muscle Group

A two-way repeated measures ANOVA with between subjects factors of sex (females, males) and balance test (SEBT, LqYBT) was conducted on the combined averaged activation of knee stabilizer muscle group (rectus femoris, hamstring, and gastrocnemius) of the forward phase of the posterolateral reaching direction of the two balance tests. Neither balance test, *F*(1,24) = 2.746, *p* = .111, partial $\eta^2 = .103$, nor sex, *F*(1,24) = 1.599, *p* = .218, partial $\eta^2 = .062$, had a statistically significant effect on the activation of the tested knee stabilizers muscle group. Also, the interaction between the two factors was non-significant, *F*(1,24) = .064, *p* >0.05, partial $\eta^2 = .003$ (see Figure 12).

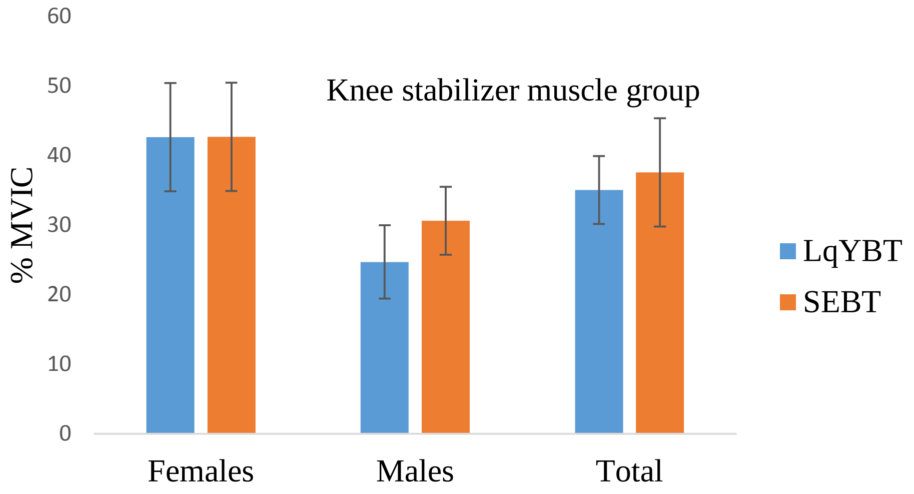

Figure 12. Posterolateral reaching direction peak normalized EMG amplitudes of the knee muscle group expressed as % MVIC.

Kinematics of the Posterolateral Reaching Direction of the Balance Tests

Kinematic data of the stance leg hip and the knee joints were obtained at the point where the participant reached the farthest distance in the posterolateral direction of the two balance tests. The SEBT farthest reaching distance point was indicated as the point of the initial ground touch of the reaching leg. The LqYBT farthest reaching distance point was indicated as the point where the participant stopped sliding the LqYBT block any farther with the reaching leg. Descriptive statistics for these analyses are presented in Table 4.

Variable	LqYBT			SEBT		
	Females	Males	Total	Females	Males	Total
	M SD	*M SD*	*M SD*	*M SD*	*M SD*	*M SD*
Hip flexion (°)	68.4±6.30	58.7±8.20	64.3±8.60	67.7±7.40	62.6±90	65.5±8.30
Hip Abd/Add(°)	31.8±8.00	33.4±8	32.5±8	27.4±10.3	27.3±8.70	27.4±9.50
Knee Flexion (°)	118.7±12	117.3±10	118.1±11	122±7.60	118.5±9.2	120.5±8.3
Knee Abd/Add(°)	15.6±14.1	14.1±8	15±11.7	8.7±70	10.6±5.40	9.5±6.20

Note: Female (N= 15), males (N= 11). Abduction/Adduction (Abd/Add) are presented as absolute angles. All angles are presented in degrees (°).

Hip Flexion

Differences in the hip flexion angle at the point of the farthest posterolateral reaching distance of the SEBT and the YBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The analysis yielded a non-significant difference in hip flexion between the two balance tests, $F(1,24) = 2.241$, $p = .147$, partial $\eta^2 = .085$. However, there were statistical differences between males and females, $F(1,24) = 6.748$, $p = .016$, partial $\eta^2 = .219$. Also the results showed that the interaction of the balance test and sex was significant, $F(1,24) = 4.501$, $p = .044$, partial $\eta^2 = .158$ an. Post hoc pair sample *t* test indicated significant differences in hip flexion angles between females and male participants. Male participants had a higher average anatomical hip flexion (*M* = 31.31°, SD = 8.28°) when they performed the LqYBT in comparison to female participants (*M*= 21.60°, SD = 6.35°). Descriptive statistics for these analyses are presented in Table 4.

Hip Abduction/Adduction

Differences in the hip abduction/adduction range of motions at the point of the farthest posterolateral reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The results yielded a significant difference between the balance tests, $F(1,24) = 5.092$, $p =.033$, partial $\eta^2 = .175$, indicating that the participants had a higher average hip abduction/adduction range of motion while performing the LqYBT when compared to the SEBT. However, there were no significant differences between males and females performance, $F(1,24) = .085$, $p =.773$, partial $\eta^2 = .004$, nor in the interaction between the two factors, $F(1,24) = .728$, $p = .124$, partial $\eta^2 = .063$ an. Descriptive statistics for these analyses are presented in Table 4.

Knee Flexion

Differences in the knee flexion angle at the point of the farthest anterior reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance test (SEBT, LqYBT), and a between-subjects factor of sex (females, males). The analysis yielded a non-significant difference in knee flexion between the two balance tests, $F(1,24) = 2.174$, $p =.153$, partial $\eta^2 = .083$. The knee flexion angle differed significantly between males and females, $F(1,24) = 5.648$, $p =.026$, partial $\eta^2 = .190$. Female participants had higher average knee flexion than male participants in both tests. The interaction between the two factors was not statistically significant, *F*(1,24) = 1.238, *p* = .592, partial η^2 = .277. These findings suggest that participant's knee flexion angle did not differ between the two balance tests. Descriptive statistics for these analyses are presented in Table 4.

Knee Abduction/Adduction

Differences in the knee abduction/adduction range of motion at the point of the farthest posterolateral reaching distance of the SEBT and the LqYBT were analyzed using a mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT), and a between-subjects factor of sex (females, males). A significant main effect of the balance test type influenced the knee abduction/adduction range of motion, *F*(1,24) = 5.317, *p* =.030, partial η^2 = .181. Participants' knee abduction/adduction range of motion was higher during the performance of the LqYBT as compared to the performance of the SEBT. However, there was no significant effect of sex, *F*(1,24) = .004, *p* =.984, partial η^2 = .00, nor in the interaction between balance tests and sex was significant, *F*(1,24) = .564, *p* = .460, partial η^2 = .023. Female and male participants' knee abduction/adduction range of motion did not differ between the two balance tests. Descriptive statistics for these analyses are presented in Table 4.

Reaching Distance

The following results addressed the third research question:

- To what extent are there differences between the SEBT and the LQYBT in reaching distance in all three tested directions? Are there any differences between males and females?

The independent variables of this study were balance tests with two levels (SEBT, YBT), and sex with two levels (males, females). The dependent variable was the normalized reaching distance of the test direction. A series of mixed-design ANOVAs were conducted to indicate the differences in the three reaching distances between the two balance tests. Descriptive statistics of the reaching distances are presented in Figure 10.

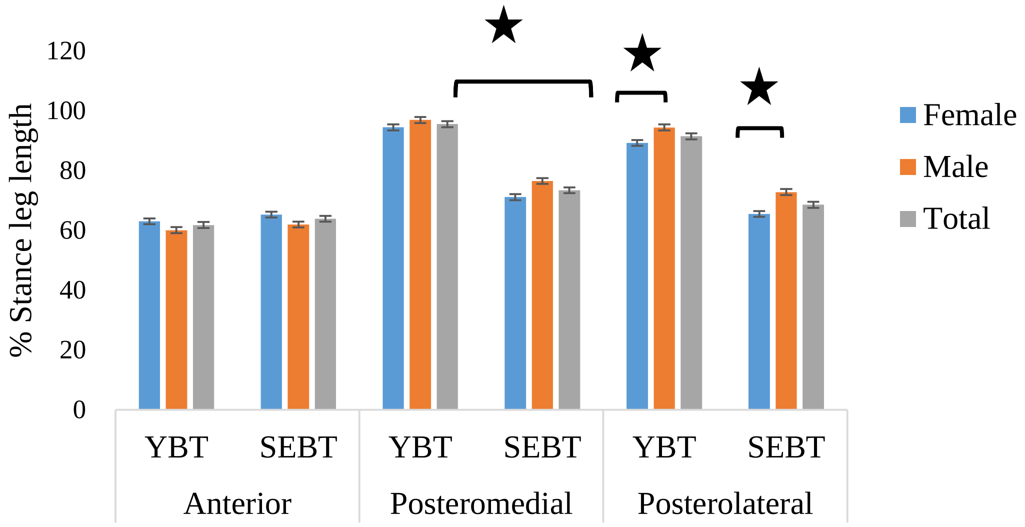

Figure 13. Normalized Reach distances as %age of stance leg length (SLL) for the two balance tests: Y Balance Test (LqYBT) and Star excursion balance test (SEBT). ★ Denotes significant differences between the means of the indicated means of each direction (*p* ≤0.05 level).

Anterior Reaching Distances

A mixed-design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT) and a between-subjects factor of sex (females, males) was conducted to assess differences in the normalized reaching distances of the anterior reaching direction. The results showed that the averaged, normalized, anterior reaching distances were not significantly different between the two balance tests, $F(1,24) = 2.909$, $p = .101$, partial $\eta^2 = .108$, and between sex, $F(1,24) = 3.65$, $p = .068$, partial $\eta^2 = .132$. Also, the interaction between the two factors was not statistically significant, $F(1,24) = .076$, $p = .786$, partial $\eta^2 = .003$, suggesting that the anterior normalized reaching distance did not significantly differ within the two balance tests nor between male and female participants (see Figure 13).

Posteromedial Reaching Distances

A mixed- design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT) and a between-subjects factor of sex (females, males) was conducted to assess differences in the normalized reaching distances of the posteromedial reaching direction. The results showed that there are statistically significant differences in the participants reaching distances between the two balance tests, $F(1,24) = 166.7$, $p < .0001$ partial $\eta^2 = .874$. In particular, participants reached farther when they performed the LqYBT than when they reached on the SEBT. Also, the interaction between the two factors was statistically significant, $F(1,24) = 5.07$, $p = .034$, partial $\eta^2 = .175$. However, participants' sex did not affect the posteromedial reaching distances $F(1,24) = 4.06$, $p = .055$, partial $\eta^2 = .145$ (see Figure 13).

Posterolateral Reaching Distances

A mixed- design ANOVA with a within-subjects factor of balance tests (SEBT, LqYBT), and a between-subjects factor of sex (females, males) was conducted to assess differences in the normalized reaching distances of the posterolateral reaching direction. The results showed that there are statistically significant differences in the participants reaching distances between the two balance tests, $F(1,24) = 227.75$ $p <. 0001$ partial $\eta^2 = .905$. In particular, participants reached farther when they performed the LqYBT than when they reached on the SEBT. Participants' sex also had a significant effect on the reached distance, $F(1,24) = 5.539$, $p = .027$, partial $\eta^2 = .188$. The male participants reached farther in both tests than the female participants. However, the interaction between the two factors (balance test type, sex) was not statistically significant, $F(1,24) = .504$, $p = .484$, partial $\eta^2 = .021$ (see Figure 13).

Regression Analysis of the Anterior Reaching Direction

A multiple regression analysis was conducted to determine which independent variables (hip flexion angle, adduction/abduction, knee flexion, and knee adduction/abduction) predicted the anterior reaching distance of the LqYBT. Regression results indicated that the overall model of the four predictors did not significantly predict the anterior reach distance of the LqYBT, $R^2 = .148$, $R^2_{\text{adj}} = -.014$, F(4,21) =.915, $p > .05$. This model accounted for only 14.8% of the reaching distances.

A multiple regression analysis was conducted to determine which independent variables (hip flexion angle, adduction/abduction, knee flexion, and knee adduction/abduction) predicted the anterior reaching distance of the SEBT. Regression results indicated that the overall model of the four predictors did not significantly predict the anterior reach distance of the SEBT, $R^2 = .161$, $R^2_{\text{adj}} = -.001$, $F(4,21) = 1$, $p > .05$. This model accounted for only 16.1% of the reaching distances.

A multiple regressions analysis was conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted the anterior reaching distance of the LqYBT. Regression results indicated an overall model of the four predictors did not significantly predict the anterior reach distance of the YBT, $R^2 = .193$, $R^2_{\text{adj}} = -.009$, $F(5,20) = .955$, $p > .05$. This model accounted for only 19.3% of the reaching distances.

Additional multiple regressions analysis was conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted the anterior reaching distance of the SEBT. The regression results indicated that the overall model of the four predictors did not significantly predict the anterior reach distance of the SEBT, $R^2 = .198$, $R^2_{\text{adj}} = -.013$, $F(5,20) = .943$, $p > .05$. This model accounted for only 19.8% of the reaching distances.

Regression Analysis of the Posteromedial Reaching Direction

A multiple regression analysis was conducted to determine which independent variables (hip flexion angle, adduction/abduction, knee flexion, and knee adduction/abduction) predicted the posteromedial reaching distance of the LqYBT. Regression results indicated that the overall model of the four predictors did not significantly predict the posteromedial reach distance of the LqYBT, $R^2 = .242$, $R^2_{\text{adj}} = .97$, $F(4,21) = 1.675$, $p > .05$. This model accounted for only 24.2 % of the reaching distances.

A multiple regression analysis was conducted to determine which independent variables (hip flexion angle, adduction/abduction, knee flexion, and knee adduction/abduction) predicted the posteromedial reaching distance of the SEBT. Regression results indicated that the overall model of the four predictors did not significantly predict the posteromedial reach distance of the SEBT, $R^2 = .111$, $R^2_{\text{adj}} = -.059$ $F(4,21) = .651$, $p > .05$. This model accounted for only 11.1% of the reaching distances.

A multiple regression analysis was conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted the posteromedial reaching distance of the LqYBT. Regression results indicated that the overall model of the four predictors did not significantly predict the posteromedial reach distance of the LqYBT, $R^2 = .139$, $R^2_{\text{adj}} = -.076$, $\mathrm{F}(5,20) = .667$, $p > .05$. The calculated model accounted for 13.9 % of the reaching distances.

A multiple regression analysis was conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted the posteromedial reaching distance of the SEBT. Regression results indicated that the overall model of the four predictors did not significantly predict the posteromedial reach distance of the SEBT, $R^2 = .057$, $R^2_{\text{adj}} = -.178$, F(5,20) = .243, $p > .05$. The calculated model accounted only for 5.7% of the reaching distances.

Regression Analysis of the Posterolateral Reaching Direction

A multiple regression analysis was conducted to determine which independent variables (hip flexion angle adduction/abduction, knee flexion, and knee adduction/abduction) predicted the posterolateral reaching distance of the LqYBT. The regression results indicated that the overall model of the four predictors did not significantly predict the posterolateral reach distance of the YBT, $R^2 = .317$, $R^2_{\text{adj}} = .187$, $F(4,21) = 2.433$, $p > .05$. This model accounted for only 31.7% of the reaching distances.

A multiple regression analysis was conducted to determine which independent variables (hip flexion, hip adduction/abduction, knee flexion, and knee adduction/abduction) predicted the posterolateral reaching distance of the SEBT. The regression results indicated that the overall model of the four predictors significantly predicted the posterolateral reach distance of the SEBT $R^2 = .384$, $R^2_{\text{adj}} = .266$, $F(4,21) = 3.27$, $p < .05$. This model accounted for 38.4% of the reaching distances.

Table 5.

Multiple linear regression model predicting posterolateral reaching distances of the SEBT.

Predictors	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
(Constant)	102.154	19.410		5.263	.000	61.787	142.520
Hip adduction/abduction	.290	.152	.340	1.903	.071	-.027	.607
Knee adduction/abduction	-.129	.263	-.099	-.491	.628	-.676	.418
Knee flexion	-.333	.127	-.509	-2.622	.016	-.598	-.069
Hip flexion	.090	.176	.093	.514	.612	-.275	.455

Dependent Variable: SEBT posterolateral reaching distance.

(N = 26)

Statistical Significant is indicated at $p \leq 0.05$

A multiple regression analysis was conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted the posterolateral reaching distance of the LqYBT. The regression results indicated an overall model of the four predictors did not significantly predict the posterolateral reach distance of the LqYBT, $R^2 = .146$, $R^2_{\text{adj}} = -.068$, $F\,(5,20) = .682$, $p > .05$. The calculated model accounted for only 4% of the reaching distances.

A multiple regression analysis was conducted to determine which independent variables (passive hip flexion angle, passive hip adduction and abduction, passive hip extension, and passive knee flexion) predicted the posterolateral reaching distance of the SEBT. The regression results indicated an overall model of the four predictors did not significantly predict the posterolateral reach distance of the SEBT, $R^2 = .04$, $R^2_{\text{adj}} = -.200$, $F\,(5,20) = .127$, $p > .05$.

CHAPTER V

DISCUSSION

The LqYBT and the SEBT are functional performance balance tests that are based on quantitative test scores with little or no reference to the quality of the performance. These balance tests measure the distance in which one can extend his/her center of gravity over the base of support in different directions (anterior, posteromedial and posterolateral), for the purpose of quantifying the limitations of postural control (Flanagan, 2012). Thus, the majority of the previous research focused on evaluating the reaching distances of the two tests and reported that only the anterior reaching directions significantly differed between the two tests and between males and females, and positively correlated with the lower extremity injury risk (Herrigton et al., 2009).

A possible explanation for the non-significant differences between the LqYBT and the SEBT in the posteromedial and posterolateral direction is that reaching distances of the functional performance tests can be achieved by a variety of compensatory movement strategies, and these different strategies do not directly affect the achieved reaching distances. Moreover, participants might have applied different movement strategies to perform each test (Coughan, 2012). Different movement strategies could relate to muscular synergy and activation, motor control, skill development, and sex of the participant (Filipa et al., 2010; Hertel et al., 2006; Plisky, 2008; Gribble et al., 2010; Sabin et al., 2010). Thus, further research on the applied movement strategies and kinematic demands related to these tests, provides insight on which tests or test directions might be more appropriate to screen or diagnose healthy recreational active participants.

The current study aimed to examine the differences between anterior, posteromedial, and posterolateral reaching directions of the LqYBT and the SEBT performances regarding lower extremity muscle activation, hip and knee joints kinematics, and reaching distances. To the knowledge of the researcher, this is the first study that included the comparison between female and male performances of the LqYBT and the SEBT in all three reaching directions. This research study also investigated the correlations between passive hip and knee joint range of motion and the achieved reaching distance in each direction.

Functional joint stabilization depends on the co-activation of the agonist and antagonist muscles surrounding the joint. This study examined hip and knee stabilizing muscles (gluteus medius and adductor magnus; biceps femoris, rectus femoris, gastrocnemius) during the SEBT and LqYBT tests. The following provides an explanation of the results as it relates to the comparison of the anterior reaching direction, posteromedial reaching direction, and the posterolateral reaching direction between the two balance tests.

Anterior Reaching Direction

Anterior Reaching Direction

Anterior Reaching Distances. Research studies focusing on investigating the differences between the LqYBT and the SEBT, reported that the anterior reaching distance significantly differed between the two tests (Coughlan et al., 2012; Fullam et al., 2013). The results of these studies did not concur with the current findings, where non-statistically significant differences were observed between the two balance tests. The lack in agreement between the current study and the previous literature could be related to the differences in postural-control strategies that participants used in preforming the balance tests.

Moreover, there is inconsistency in the existing literature about the SEBT anterior reaching distance differences between females and males. Robinson and colleagues (2009) and Gribble and colleagues (2009) reported that female participants outperformed male participants in the anterior reaching direction of the SEBT (Robinson et al., 2009, Gribble et al. 2009). Others did not find statically significant differences in the SEBT anterior reaching distance between females and males (Sabin et al., 2010) ;Kahle & Gribble (2009); Gribble & Hertel, 2003). Also, Chimera and colleagues (2015) did not find any difference in the anterior reaching direction between males and females LqYBT performance.

The findings of the current study did not indicate any statically significant differences between females and males anterior reaching distances of the balance tests. Although not significant, the female participants on average reached slightly farther in both tests LqYBT (*M* = 65.3, *SD* = 3.4) SEBT (*M* = 63.08, *SD* = 4.38) compared to male participants LqYBT (*M* = 62, *SD* = 5.9) and SEBT (*M* = 60.38, *SD* = 6.08) thus supporting the findings of Robinson and Gribble.

Kinematics

Hip Kinematics. It has been established from the previous research studies that hip flexion is the essential kinematic predictor of the performance of the dynamics balance tests, LqYBY (Kang, Kim, Kwon, Weon, Oh, & An, 2015) and the SEBT (Robinson & Gribble 2008). Researchers have explored the differences in hip flexion between the LqYBT and the SEBT anterior reach and found that the performance on the LqYBT was characterized with greater hip flexion compared with the performance of the SEBT (Coughlan et al., 2012, Fullam et al., 2014). These previous studies included either male participants (Fullam et al., 2014), or a mixed sample of female and males participants (Coughlan et al.,2012).

The current study demonstrated that the significant interaction between dynamic balance test type (LqYBT, SEBT), and participants' sex (females, males) influenced hip flexion during the anterior reaching direction. Regarding the means of the averaged hip flexion, female participants had a higher averaged acute flexion angle (*M*= 63.61°, *SD* = 4.7°) when performing the anterior reach of the SEBT which represent lower hip flexion angles compare to the LqYBT (*M*= 60.07°, *SD*= 8.02°). Meanwhile, the performance of the male participants concurs with the previous studies, demonstrating greater flexion acute angle at the point of maximum reach during performance of the anterior reach direction of the YBT (*M*= 62.46°, *SD*= 7.1°) which represent lower hip flexion angle compared to the SEBT (*M*= 59.76°, *SD*= 6.2°).

The differences in hip flexion between the two balance tests could be related to the nature of the performance of the LqYBT compared to the SEBT. The LqYBT anterior reaching is initiated by contacting the distal aspect of the reaching foot with the indicator block and sliding it. This action is predominantly achieved by flexing the hip and knee joints of the stance leg (Fullam et al., 2012; Chimera &Warren, 2016). Whereas, at the beginning of the anterior reach direction of the SEBT, the participant initiated the action by lifting the reach leg and moving it along the ground, until the distal part of the reach foot touched the ground. For this condition, the demand of hip flexion on the stance leg was minimal (Robinson & Giribble, 2008; Fullam et al., 2012; Chimera &Warren, 2016; Earl & Hertel, 2001). Moreover, the performance of the SEBT required the participant to slightly touch the ground with the most distal part of their reaching foot at the farthest anterior reaching distance. To control this movement, participants were inclined to limit the motion of the center of mass (less anterior displacement) over the stance leg, by limiting their trunk/ torso movment and trying to keep it as straight (extended upright) as possible(Fullam et al., 2014). Although upper extremity position was not analyzed, previous research has hypothesized that the observed decreased hip flexion while performing the anterior reach direction of the SEBT may result in less anterior displacement of participants' center of mass (Fullam et al., 2014); it could be hypothesized that differences in hip flexion between the two balance tests could decrease the anterior translation of the center of mass and created a counterbalance mechanism for the reaching leg that might allow for farther reaching performance of the SEBT compared to the LqYBT. Moreover, the differences between the reaching directions of the two balance tests could be related to the elevated stance position of the LqYBT, where participants are required to stand on an elevated center platform. This could have created an unstable surface, creating a perceived barrier to achieving the reaching distance. It has been proposed that an unstable testing surface challenges the somatosensory mechanism of postural control (Coughlan et al., 2012). Sabin and colleagues examined the changes in SEBT reaching distance tested on unstable surfaces and found 4.5% to 9% farther reaching distances when performing the SEBT on a stable surface (Sabin et al., 2010).

Hip adduction/abduction. The current study demonstrated that participants had a significantly higher hip adduction/abduction range of motion while performing the LqYBT as compared with the SEBT. Also, a statistically significant interaction was found between balance tests and participants' sex. Female participants had a higher hip abduction/adduction range of motion compare to males. This could indicate that LqYBT challenged participants' hip stability more than the SEBT. Previous literature did not report the differences in hip adduction/abduction range of motion between the LqYBT and the SEBT. However, (Kange et al.,2015) reported that preforming the anterior direction of the LqYBT, thirty physically active participant (22 men and 8 women) had an abducted hip *(M* = 8.83, *SD* = 3.84). Differences in the hip adduction/abduction range of motion between (Kange et al.,2015) study and the current study could be due to the differences in the anterior reaching distances. Kange et al.,2015 participants reached anteriorly shorter (*M*= 59.42, *SD* = 5.59) than the current study participants (*M* = 63.9, *SD* = 4.82), which might suggest that achieving further reaching distances participants father challenged their limits of stability. Hip adduction/abduction during the performance of the anterior reaching direction of the SEBT were investigated by Delahunt and college 2013, were they compared the performance of the SEBT between female athletes who have undergone ACL reconstruction and a healthy group. The results of the fourteen recreational females showed had averaged lower hip adduction when preforming the anterior reaching direction of the SEBT approximately (3.5 degrees) compare with the current study females performance. The differences between the studies could be related to the differences in achieved distances where further reaching anterior distance were reported in the study of (Delahunt et al.2013) females healthy group participants (*M* = 71.25, *SD* = 4.34) than the female participants of the current study (*M*= 65.3, *SD* =3.4). Farther reaching distances during the performance of the SEBT has been related to better postural control, thus, it might be that (Delahunt et al.2013 participants had better postural control (Coughlan et al. 2012; Fullam et al., 2014).

Hip muscle activation. Neuromuscular control during the performance of the dynamic balance tests, particularly the SEBT, has been associated with archived reaching distances (Norise et al., 2011). An increase in reaching distances reflects better neuromuscular control. It has also been reported that alterations in muscle activation occur as a result of fatigue or training effect. Two previous studies investigated lower extremity muscle activation profiles to determine their contribution to the performance of the SEBT (Earl & Hertel., 2001; Norris & Trudelle-Jackson, 2011). Both studies indicated that muscle activation of the lower extremity during the performance of the SEBT is direction dependent. Moreover, it has been shown that decreased activation at the hip is associated with decreased activation of the rectus femoris and the biceps femoris, which limits the dynamic stability of the knee joint (Griffin et al., 2000; Rosene et al., 2001; Zeller et al., 2003).

A novel aspect of this study examined the differences in the frontal plane of the musculature that act to stabilize the hip (gluteus medius, adductor magnus). When muscles were grouped as one unit, the results revealed non-statistically significant differences in the activation between the LqYBT and the SEBT. However, the results of this study indicated a statistically significant interaction for gluteus medius between the balance tests and participants' sex. Female participants had a higher activation of the gluteus medius (33.68% MVIC) during the performance of the LqYBT compare to the SEBT (30.54%MVIC). The male participant's demonstrated higher activation of the gluteus medius during the performance of the SEBT (32.84%MVIC) compared to their performance on the LqYBT (22.69% MVIC). Similar results have been reported in the study by Norris & Trudelle-Jackson (2011), in the activation of the gluteus medius during the performance of the anterior reaching distance of the SEBT. The anterior reaching distances of the SEBT in the current study was lower than what has been reported previously in the research studies that examined the muscle activation during the performance the SEBT (Earl & Hertel, 2001; Norris & Trudelle-Jackson, 2011). Thus, the comparison between the muscle activation might be inappropriate. Moderate activation of the gluteus medius during the performance of the anterior reaching distance has been suggested to promote pelvic stability (Vezina &Hubley-Kozey.2000; Norris & Trudelle-Jackson, 2011). With reference to the results of the hip adduction/abduction of this study, female participants had less hip abduction/adduction during the performance of the LqYBT, which could relate to the higher activation in the hip musculature. This resulted in better control of the hip frontal plane stability, while performing the LqYBT compared to the SEBT.

Knee stability muscle group

The current study investigated that activation of the knee stability musculature (rectus femoris, hamstring, and gastrocnemius) during the performance in the anterior direction of the LqYBT and the SEBT. In addition, a knee muscle group was created from the combination of the previous muscles in an attempt to compare their group activation. The results revealed non-statically significant differences during the performance of the anterior reaching direction of the previous muscles except for the gastrocnemius. Only during the anterior reaching direction was there a statistically significant difference in the activation of the gastrocnemius muscle between females and male participants. The female participants had a higher activation for both tests. Post hoc tests indicated that the significant statistical differences were found on the performance of the SEBT between females and males. These results could be related to the amount of stance leg foot motion during the task, where participants lifted either the heel or the forefoot from the surface. Although the investigator asked participants to minimize the foot motion as much as possible and avoid lifting their heels, it was hard to eliminate the foot motion completely. LqYBT testing protocol allows for foot motion during the reaching tasks. Increased activation of the gastrocnemius could indicate an increased demand for ankle stability and control during the balance tests that incorporate the hip and upper extremity counterbalance (Plisky, 2009).

Posteromedial Reaching Direction

Reaching Distance

During the performance of the posteromedial reaching direction, statistically significant differences were observed between the two balance tests. Participants reached farther during the performance of the LqYBT (*M* = 91.49, *SD* = 8.21) compared with the SEBT (*M* = 63.92 *SD* = 4.82). These results did not support earlier findings of Coughlan and colleagues (2012) where no significant differences were found for the posteromedial and posterolateral reaching directions between the LqYBT and the SEBT. The difference between the current findings and Coughlan's (2012) study was the participant sample. In the current study, the performance of both males and females were analyzed, while Coughlan and his colleagues only examined the performance of male participants.

Although male participants posteromedial reaching distances did not significantly differ from female participants, males reached farther in both tests, LqYBT (*M* = 94.47%, *SD* = 9 %) and SEBT (*M* = 72.83 *SD* =8.03 %) compared with females LqYBT (*M* = 89.3% *SD*= 7.11 %) and SEBT (*M* = 65.53%, *SD* = 6.88 %). However, it should be noted that the results of the current study did not concur with the findings of Gribble and colleagues (2012). Their results demonstrated a significant interaction for sex and time, during the performance of the posteromedial reaching direction of the SEBT, whereas, female participants reached farther than the male participants (Gribble et al., 2009). These results were in agreement with Alnahdi, Alderaa & Aldali (2015), where they reported that young healthy male participants reached farther than females in all three directions of the LqYBT. Also, the result of the current study agreed with the work of Engquist and his colleagues (2015), where they compared the LqYBT performance of student-athletes with general college students and reported that male participants had greater posteromedial reach distance than females.

Postural control depends on the sensory inputs from the muscular, vestibular, and visual systems. The sensory feedback is used in the development of postural adjustments and to maintain the body's center of mass within the base of support. The visual system is an integral source of feedback, which provides information to anticipate and prepare for upcoming perturbations. All sensory inputs are translated into data of balance status and orientation requirements within the Central Nervous System (CNS). Under the condition of limited visual feedback, the CNS depends on the proprioceptive inputs, influencing the neuromuscular control and the applied movement patterns (Kinzey & Armstrong, 2008; Ghez, Gordon & Ghilardi, 1995). In the absence of visual feedback during the performance of reaching tasks, spatial orientation and proper postural control is maintained through the development of an internal model that depends on the proprioceptive (Redfern, Moore & Yarsky, 1997). Therefore, it could be suggested that the statistically significant differences between the two balance tests are related to the amount of obtained sensory feedback. During the performance of the posteromedial reaching direction, participant's visual feedback was limited, as they tended to keep their body oriented forward. When performing the LqYBT, participants are required to keep in touch with the sliding indicator which could provide additional information regarding the position of the lower limb achieved by the proprioceptive mechanisms. Proprioceptive feedback during the performance of posteromedial reaching of the LqYBT would provide additional information to control the center of gravity during the reaching task, creating a more stable base of support for farther reaches compared to the SEBT (Riemann & Lephart 2002; Coughlan et al., 2012; Coughlan et al., 2014).

Previous research studies reported that improvement in the posterolateral and posteromedial direction are more likely to be the result of improved neuromuscular control and dynamic balance, rather than strength (Thorpe & Ebersole, 2008; Herringtone et al., 2009; McLeod et al., 2001; Zech, Hübscher, Vogt, Banzer, Hänsel, & Pfeifer 2010). That also could explain the non-significant differences found in the reaching directions between females and males. In a study conducted by Robinson and Gribble (2008), it was suggested that better-reaching distances in the SEBT were not correlated to strength or core stability but, rather, to increased knee and hip flexion for the stance limb. They examined 20 healthy university participants, who did not undergo any intervention program. Stepwise regression indicated that hip and knee sagittal plane kinematics, separately and in combination, explained 62% to 95% of the variance in the reach distances (Robinson & Gribble, 2008). Concluding that, postural control is maintained through the integration of sensory-motor information and the execution of the appropriate musculoskeletal responses.

Hip Kinematics

Examining hip kinematics, specifically hip flexion during posteromedial reaching, the current study revealed a statistically significant difference between the LqYBT and the SEBT. Participants had, on average, greater hip flexion when preforming the SEBT (*M* = 61°, *SD* =7.3°) than they did performing the LqYBT (*M*= 59.7°, *SD* = 7.2°). Additionally, it should be noted that previous research has reported that hip flexion is a strong predictor of LqYBT posteromedial reaching performance (Delahunt, Chawke, Kelleher et al., 2013; Kang et al., 2015). This finding suggests that those with greater hip flexion achieved greater posteromedial reaching distances. These differences between the two balance tests could be related to the nature of the tests. It is suggested that the LqYBT requires a higher demand for postural control than the SEBT, as the sliding block must be pushed into position, whereas the SEBT simply requires toe pointing. As explained earlier, hip flexion could have affected trunk position (e.g. flexion), which affected the position of center of body’s mass. Throughout the testing it was noted that during the posteromedial reaching direction of both tests, participants tended to perform trunk flexion to maintain the center of mass over the base of support creating a strategy to correct balance

(Reeves, Everding, Cholewicki and Morrisette 2006; Kang et al., 2015). The results of the current study also indicated statistically significant differences between female and male participants’ hip flexion. Female participants tended to have higher flexion during the performance of the posteromedial reaching direction of the LqYBT (*M*= 62.2°, *SD* = 7°) and for the SEBT (*M* = 63°, SD =7.6°) compared to male participants LqYBT (*M* = 56.2°, *SD* = 6°) and SEBT (*M*=58°, *SD* = 6°). It has been postulated that greater hip flexion for female participants during the posteromedial direction resulting in decreased reaching distance, could indicate insufficient controlling of the trunk with greater hip flexion (Robinson & Girbble, 2008). In addition, it has been reported that the combination of hip flexion and contralateral trunk flexion play an important role in maintaining balance during the performance of LqYBT (Kang et al., 2015). Insufficient controlling of the hip stability has been related to lower reaching direction in the SEBT (Couglan et al., 2012; Coighlan et al., 2014).

The performance of the posteromedial reaching direction is performed in a diagonal plane necessitating multiple plan postural control strategies to counterbalance. The greater hip flexion values observed during the posteromedial reaching direction of LqYBT were also accompanied with a statistically significant increase in hip adduction/abduction over the stance leg. Posteromedial reaching direction is performed by extending the reaching leg backward and crossing over the stance leg. Increased hip sagittal and frontal plane motion created a Trendelenburg position, resulting in the lengthening of the reaching leg and subsequently increased the reaching distances (Zeller et al., 2003; Delahunt et al., 2013).

Muscle Activation

The posteromedial reaching direction performance did not indicate any significant difference in the tested muscle activation or grouped muscle activation of the hip or the knee joints except for the activation of the rectus femoris. Rectus femoris activation significantly differed between the two balance tests. Higher activation was indicated during the performance of the SEBT (*M* = 62.01%, *SD* = 36.43 %MVIC) compared to the LqYBT (*M* = 49.08%, *SD* = 28.32%MVIC). The activation of the rectus femoris is important to maintain stability, during the eccentric phase of the reach as it countered the knee flexion torque (Perry & Burnfiled, 2010; Hesari et al., 2012). This could suggest that different movement strategies have been used during the performance of the posteromedial reaching distance between the LqYBT and the SEBT. Researchers have suggested that decreased activation at the hip is associated with decreased activation of the rectus femoris and the biceps femoris, which limits the dynamic stability of the knee joint (Griffin et al., 2000; Rosene et al., 2001; Zeller et al., 2003). Whereas, increased activation of the rectus femoris might indicate that the SEBT test challenged participants' hip stability more, by increasing the demands on the gluteus medius due the nature of the movement. Indicating that the SEBT might trigger the activation of the rectus femoris to control the knee more than the LqYBT. These results are in agreement with the results of Norris & Trudelle-Jackson (2011) where they indicated that the performance of the SEBT posteromedial reach direction, increased the activation of the vastus medialis (VM), in comparison with the other reaching direction. Also, they recommended the performance of this direction to elicit strengthening of the rectus femoris (Norris & Trudelle-Jackson, 2011). Similar results were reported by Eral and Hertel (2001). This could be related to the observed increase knee and hip adduction/abduction during the performance of the LqYBT compared to the SEBT in the current project. Increased frontal plane kinematics of the hip, creates a compensatory mechanics that increases the demands to stabilize the knee joints (Delahunt et all., 2013) Specifically, adduction of the hip and internal rotation of the femur places the knee into a valgus position which might elicit changes in the position of the body’s center of gravity affecting participants limit of stability range of motion.

Posterolateral Reaching Direction

Reaching Distance

The posterolateral reaching direction is simulated when moving backwards such as when playing defense in various sports (e.g., basketball, soccer). Thus, indicating that the postural control in the posterolateral direction could be important in screening for performance quality for sport and recreational activities. The current study results indicated that participants reached statistically farther for the posterolateral reaching distance when performing the LqYBT (*M* = 91.48%, *SD* = 8.21% SLL) when compared to the SEBT (*M* = 68.62%, *SD* = 8.11% SLL). Moreover, significant differences in reaching distances were also observed between male and female participants. The males reached farther in both tests compared to female participants for the YBT (*M* = 94.47%, *SD* = 9% SLL) compared to females (*M* = 89.3%, *SD* = 7.11%SLL), SEBT males (*M* = 72.83%, *SD* = 8.03%SLLL) compare to females (*M* = 65.53%, *SD* = 6.88%SLL) respectively.

Previous literature showed no consistency in the impact of participants’ sex on the posterolateral reaching distance. Sabin and colleagues (2010) reported that male participants reached 7% farther posteriorly during the performance of the SEBT than the females, which supports the findings of the current study. On the other hand, the results of this study did not agree with the results of Gribble’s (2009) study, which showed that for the posterior reaching direction, females reached farther than male participants when they tested at the baseline and after applying different fatigue protocols. Gribble and Hertel (2003) did not indicate a significant difference in the normalized reaching distances between males and females.

Kinematics

Hip Kinematics

Posterolateral reaching direction was associated with statistically significant increased hip and knee abduction/adduction during the performance of the LqYBT compared to the SEBT. Knee and hip flexion displayed a statistically significant interaction between balance tests and the participants' sex. With reference to the current research results of the posterolateral reaching distances, it could be suggested that farther reaching distance achieved while preforming the LqYBT compared to the SEBT might be related to the position of the hip. Increased hip adduction/abduction and flexion creates a Trendelenburg pose (hip drops down on the reaching leg side), allowing for an extra extension of the reaching leg, if associated with good control of the knee.

Knee Kinematics

Knee angular position, either in the frontal plane (knee adduction abduction) or in the sagittal plane (knee flexion) significantly affected the postural stability and the performance of the LqYBT and SEBT. As explained earlier, increased knee flexion has been linked to farther reaching distances. In the current study, statistically significantly differences in knee joint flexion and abduction/adduction were indicated between the performances of the female and male participants. Female participants tended to have more knee flexion and knee abduction/adduction than male participants for both tests. Similar results were found in a study conducted by Gribble and colleagues (2009), whereas, female participants demonstrated greater knee flexion than males (more than 5°). In the current study, although female participants demonstrated greater knee flexion than males, their posterolateral reaching distance was less than the males. This finding could be associated with the increased knee adduction/abduction finding especially during the performance of the LqYBT. The increase in knee adduction/abduction has been related to increased knee joint loads and could influence the female participants reaching distances (Delahunt et al., 2013).

Muscle Activation

Increased activation of the gluteus medius during the posterolateral reaching direction, could be related to the nature of the task, where lateral reaching directions of the SEBT require external hip rotation and adduction. Thus, in the current study it was found that there was a significant gluteus medius muscle activation difference between males and females during the performance of the LqYBT (females: *M* = 37%, *SD* = 17.4%MVIC; males: *M* = 17.5%, *SD* = 8 %MVIC) as well as on the SEBT (females: *M* = 32.8%, SD = 18% MVIC;(males: *M* = 33.7%, *SD* = 25.7%MVIC). Moreover, statically significant interaction was indicated in the muscle activation between males and females and the test performed. Female participants had an increased gluteus medius muscle activation during the posterolateral reaching of the LqYBT compare with the SEBT, while male participants showed greater gluteus medius muscle activation during the performance of the SEBT posterolateral reaching compared with the LqYBT. Shorter posterolateral reaching distances achieved by female participants could be related to the combination of increased hip, knee abduction/adduction and higher activation of the gluteus medius compared to than male participants. Differences in activation within the same sex could indicate different levels of postural control. Higher activation of the gluteus medius is probably presented to control increased knee adduction (McCurdy, O’Kelley, Kutz, Langford, Ernest, & Torres, 2010).

During the unilateral stance, one’s center of mass shifts laterally due to gravity. The need to maintain the center of gravity within the base of support is controlled by the activation of the gluteus medias (Hwang et al., 2016). The gluteal muscle group provided postural stability by the eccentric contraction to resist generated abduction momentum, and mechanically provide the control of excessive range of motion (Comerford &Mottram, 2001). Weakness in hip stabilization, especially in the gluteus medius muscle can cause the hip to adduct when loaded. The adduction of the hip joint tends to internally rotate the femur placing the knee into a valgus position. However, some of the observed differences between sexes could be related to intrinsic biomechanical factors such as a wider pelvis in female participants, which would change the angulation of the femur (Zeller et al., 2003; McCurdy et al. 2010; Delahunt et al., 2013).

Conclusion

Lower extremity dynamic postural control is maintained through a sequence of segmental motion within the kinetic chain, encompassing range of motion, strength, coordination, and neuromuscular control of the lower extremity, especially in forming the interrelationship between the hip and knee joints (Zeller et al. 2003). Detecting the differences between the SEBT and the LqYBT may be of value to sport therapists and other professionals working in the field as it is possible to better evaluate and detect changes in balance associated with lower extremity injury. Identifying performance strategies and differences in compensation movement strategies between males and females during the performance of the SEBT and the LqYBT could help to discriminate components of injury screening and a priority in recruiting the tests during risk management strategies.

The current study extended previous research studies on the kinematic and EMG variables, which indicated the differences between the three reaching directions of the LqYBT and the SEBT. A novel aspect of this study was the investigation of the combined stabilizer muscle groups of the knee and hip in addition to looking at a single muscle activation. Also, this is the first research study that indicated a difference in the posteromedial and posterolateral reach distances between LqYBT and the SEBT within the same research study using the same healthy recreationally active population. To the author’s knowledge, only two studies have examined the differences between the LqYBT and the SEBT performance within the same study and participant population. In these studies, the researchers investigated only the kinematic differences and found significant differences in only the anterior reaching direction (Coughlan et al. 2012; Fullam et al., 2014).

The current study found statistically significant differences between the two tests in the posterolateral and posteromedial reaching direction even when applying normalization techniques. This could suggest that the outcomes of the two tests are not comparable. The results of this study could also indicate that normalized reaching distance differences between LqYBT and the SEBT, and between and within females and males suggest different strategies should be incorporated when performing these tasks. Differences in strategies applied during the performance of the LqYBT and SEBT were achieved primarily through hip kinematics and hip and knee muscular activation. The current study demonstrated that female participants had an increased amount of hip and knee abduction/adduction when performing the LqYBT compared to the SEBT. This could suggest that the LqYBT dynamic balance test is more sensitive in indicating hip and knee control among females.

It could be concluded form the current study results that the two balance tests significantly differ with respect to frontal and sagittal plane knee and hip kinematic characteristics in the posteromedial and posterolateral reaching direction. These findings suggest that using these tests interchangeably in the field or transforming outcomes between the two test might not be appropriate when assessing the postural control of healthy recreationally active populations. The posteromedial and posterolateral reaching directions are performed in a diagonal plane, facilitating a multiplane motion. Thus, future research studies should include the investigation of the transverse plane side by side with the muscle activation profiles to better understand the postural control strategies used in the performance of the two tests.

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Appendix A

Health Screening Questionnaire

Part 1. Participant Information

(Please print)

ID Number: ____________________   Height: _____ft _____in   Age: _______

Part 2. Athletic Participation

(Please circle your responses)

1. What is your dominant leg/foot?   RIGHT   LEFT

2. How many hours per week do you exercise? _____h/week

Part 3. Medical History

(Please circle your responses)

1. Are you allergic to adhesive tape or other adhesive products?

   YES   NO

2. In the past 6 months have you had surgery?

   YES   NO

3. In the past 6 months, have you had any injury?

   YES   NO

4. In the past 6 months, have you had any pain?

   YES   NO

5. Has your doctor ever said that you have a heart condition and recommended only medically supervised physical activity?
   YES NO

6. Do you lose your balance due to dizziness or do you ever lose consciousness during physical activity?
   YES NO

7. Do you have a bone, joint, or any other health problem that causes you pain or limitations that must be addressed when developing an exercise program (i.e. diabetes, osteoporosis, high blood pressure, high cholesterol, arthritis, anorexia, bulimia, anemia, epilepsy, respiratory ailments, back problems, etc.)?
   YES NO

8. Are you pregnant now or have you given birth within the last 6 months?
   YES NO

9. Do you have any chronic illness or physical limitations such as Asthma, diabetes?
   YES NO

10. Do you have any injuries or orthopedic problems such as bursitis, bad knees, back, shoulder, wrist or neck issues?
    YES NO

11. Do you take any medications, either prescription or non-prescription that affect your balance?
    YES NO

By dating, I hereby state that my answers to the above questions are complete and correct to the best of my knowledge.

Date: _______________

Appendix B

IRB Consent Form

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL
STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS
DOCUMENT.)

INFORMED CONSENT for Research Study:

Two dimensional balance test; Analysis comparison between balance performance on selected directions of Star Excursion Balance Test and Y Balance Test

You are invited to participate in a research study: to examine the differences in performance between two dynamic balance tests, regarding lower extremity joint kinematics (hip knee and ankle), and muscles activation in healthy recreational young active adults (males and females). The study is being conducted by Doctoral Candidate Mariam Abu Alim, Auburn University Department of Kinesiology. You are selected as a possible participant because you have responded to our research E-mail, and you are between the age of 19 and 35 years older, healthy with no injuries pain or surgeries within the past six months.

What will be involved if you participate? If you agree to participate in this research, you will be asked to attend two testing session with at least 24 hours apart (60-minutes per session). For testing will be asked to perform two dynamic balance tests the Star Excursion Balance Test (SEBT) and Y Balance test (YBT) one in each session. For data collection, you will be asked to wear athletic shorts and a sportswear T-shirt of your own. Both SEBT and YBT aim to measure and challenge your postural stability dynamically. During the SEBT, you will be asked to places the dominant side foot in the middle of the star pattern and then perform three maximum single-leg reaches in three directions anterior posterolateral, posteromedial. For the YBT, you will step on the standing block with the dominant leg and perform three maximum single-leg reaches, while pushing the second block with the non-dominant foot in three directions anterior posterolateral, posteromedial. Three trials in each direction will be performed, and the farthest reach distance will be registered. A comprehensive analysis of your performance (biomechanical, muscle activation and test scores) will be conducted to indicate the differences in the performance between the SEBT and YBT. Therefore, testing in this research will require the evaluation of dominant leg length. Leg length will be measured from the bony point on the pelvis (the superior anterior iliac spine) to the ankle (the medial malleolus) using a measuring tape. Once all preliminary paperwork has been completed, muscle activities will be recorded by electromyography sensors that will be placed on the dominant body side on the following muscles: gluteus medius, rectus femoris, hamstring, gastrocnemius. Manual muscle testing will then be performed as a means of normalizing all EMG data that is collected during the two balance tests. Two video cameras will be used to obtain the biomechanical (kinematic) data. To recode the test performance; one camera will be placed 3 meters in front of the participant and the other 3m at the side of the participant. Only the lower extremity will be recorded, and the video will not identify the participant ID. Your total time commitment will be approximately two hours.

Participant's Initials: ________________

Are there any risks or discomforts? As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are only minimal risks and may include: muscle strain, muscle soreness, ligament and tendon damage, and skin irritation. Every effort will be made to minimize these risks and discomforts. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing. To reduce the risk of injury, you will be given time to warm-up and testing will not begin until you deem yourself ready. Water will be provided to you as needed. If you have an allergy to adhesive products, you will not be permitted to participate. Rubbing alcohol will be used to remove all adhesive products to limit the risk of skin irritation.

Confidentiality

All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use, and will not be disclosed to any person(s) outside of the research team. The results of this study will be a part of the principal investigator dissertation. Upon completion of the dissertation, the investigators may also represent the result at national and international conference and publish the data in peer-reviewed journals. Your name or identity shall not be revealed should such publication occur.

In the unlikely event physical injury is suffered as a result of the participation in this study, the Emergency Action Plan will be followed. Auburn University does not automatically provide reimbursement for medical care or other compensation, and you will be responsible for any medical expenses.

Are there any benefits to yourself or others? Your participation in this research is completely voluntary. By participating in this study, you will receive information regarding your balance assessment scores. By receiving this information, you may be able to better utilize strengthening and balance exercises in your workout regime. The data you provide will help the researchers to expand knowledge of the dynamic balance assessments and will be used in the applicable dissertation.

Are there any costs? There is no direct cost to the participants. Any incurred medical costs are not covered through this research. You are responsible for any costs incurred during transport to/from Auburn University for testing.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the School of Kinesiology.

If you have questions about this study, please ask them now or contact or Mariam Abu Alim by phone (334)-498-6382 or e-mail at maa0033@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY.

YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

______________________________ ______________________________
Participant's signature Date Investigator obtaining consent Date

______________________________ ______________________________
Printed Name Printed Name

Appendix C

Passive range of motion test procedures

Joint Action	Testing Position	Range of Motion Test	Normal End-Feel	Goniometer Alignment
Hip flexion	The participant in supine position, hip and knee extended and with no abduction and adduction, external and internal rotations.	Knee join flexion. The examiner passively flexes the hip by lifting the thigh up.	Resistance to flexion motion is felt and attempts to further flexion causes posterior tilting of the pelvic.	Fulcrum placed laterally on the hip joint just anterior superior to the greater trochanter. The stationary arm aligned on the midline of the trunk long axis, with a reference to the greater trochanter. The moving arm is aligned with the lateral midline of the femur. With a reference to the lateral epicondyle.
Hip extension	The participant in prone position, hip and knee extended and with no abduction and adduction, external and internal rotations.	The examiner preforms hip extension by lifting the thigh up of the table. Knee joint kept extended.	Resistance to hip extension motion is felt and the attempt to further extension causes anterior pelvic tilt and/or accompanied with lumber spine extension.	Fulcrum placed on the lateral aspect of the hip joint. With reference to the greater trochanter. The stationary arm aligned on the midline of the trunk long axis. The moving arm is aligned laterally on the midline of the femur.
Hip abduction	The participant in supine position with the tested hip and knee extended and with no abduction and adduction,	The examiner passively abducts the hip by placing one hand on the lower leg (under the ankle) to	Resistance to hip abduction is felt and the attempt to further abduct the hip results in	Fulcrum placed at the anterior superior iliac spine of the tested limb. The stationary arm aligned horizontally between the ASISs.

	external and internal rotations.	prevent internal external rotation of the limb, and sliding the limb latterly.	lateral trunk flexion.	The moving arm is aligned on the long axis of the femur midline. With reference to the kneecap.
Hip Adduction	The participant in supine position, hip and knee extended and with no abduction and adduction, external and internal rotations.	The examiner passively adducts the hip by placing one hand on the lower leg (under the ankle) to prevent internal external rotation of the limb, and sliding the limb medially.	Resistance to hip adduction is felt and the attempt to further adduct the hip results in lateral pelvic tilting, rotation of the pelvic and /or trunk lateral flexion.	Fulcrum placed at the anterior superior iliac spine of the tested limb. The stationary arm aligned horizontally between the ASISs. The moving arm is aligned on the long axis of the femur midline with reference to the kneecap.
Knee flexion	The participant in supine position, hip and knee extended and with no abduction and adduction, external and internal rotations. .	The examiner flexes the hip joint approximately 90° and places one hand at the ankle to passively flex the knee by moving the ankle closer to the posterior thigh.	Resistance to further knee flexion is sensed and further knee flexion results in increased hip flexion.	The fulcrum placed at the middle of knee joint axis (lateral epicondyle). The stationary arm aligned with the midline of the femur laterally, using the greater torchon as a reference. Move arm of the goniometer aligned with the midline of the fibula laterally, using the lateral malleoli as a reference.

Appendix D

sEMG electrodes placements

The EMG electrodes will be positioned in parallel to the muscle fibers of the selected muscles. The specific electrode placement was based on Criswell's Atlas for electrode placement (2010):

Gluteus Medius: Two active electrodes (2 cm apart) are placed medial to the glute maximum muscle and over the proximal third of the distance between the iliac crest and the greater trochanter.

Adductor Magnus: Two active electrodes (2 cm apart) are placed in an oblique angle at the proximal third of the med thigh.

Rectus Femoris: Two active electrodes (2 cm apart) are placed midway the knee joint and the iliac spine.

Biceps Femoris: Two active electrodes, 2 cm apart, are placed parallel to the muscle fibers on the lateral aspect of the thigh, two-thirds of the distance between the trochanter and the back of the knee.

Bilateral Gastrocnemius: Two active electrodes (2 cm apart) are placed latterly to the midline of the posterior shank. Both electrode will be placed at the proximal end of the tibia just under the posterior aspect of the knee joint.

Appendix E

Marker positions used in the calculation of lower extremity joint kinematics

Plane of analysis	Marker position	Segment
Frontal	Right/Left Superior iliac spines (ASISs)	Pelvis
Frontal	Center of kneecap	Knee
Frontal	Midpoint of the insertion of the Achilles tendon (Posterior Calcanei)	Heel
Frontal	Center of the ankle from the front	Ankle
Sagittal	Acromioclavicular joint	Shoulder
Sagittal	Greater trochanter	Upper leg
Sagittal	Lateral femoral epicondyle	Upper leg
Sagittal	Lateral malleolus	Lower leg
Sagittal	Distal end of the 2nd metatarsal	Foot
Sagittal*	Posterior calcanei of the reaching leg	Heel

Note: All markers will be placed on the participants dominate body side.

* Marker placed on the non-dominate side.

Appendix F

sEMG electrodes placement and markers positions