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Star Excursion Balance Tests as a Measure of Functional Joint Mobility

An Exploratory Study

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Abstract

Background: The Star Excursion Balance Test (SEBT) consists of 8 directional foot reaches on each leg, and it is used to evaluate dynamic balance and postural control in single leg stance. The SEBT has been able to differentiate those with chronic ankle instability, anterior cruciate ligament injuries and other musculoskeletal deficits in the lower extremity. However, three-dimensional joint movements of the lower extremities elicited by the different foot reaches and how they correspond to normative range of motion (ROM) values have not been systematically described in the literature. Furthermore, based on available kinematic studies on the SEBT it is apparent that none of the tests elicit limited transverse plane joint movements. **Aim:** The aim of this study is to 1) perform a kinematic 3D analysis of lower extremity joints and trunk in all planes of motion during performance of the SEBT, 2) compare joint movements elicited by the SEBT with normative ROM reference values, 3) establish joint movement predictors of reach distance of the SEBT and 4) introduce two new rotational tests for evaluation of transverse plane lower extremity joint movements. **Methods:** Twenty male participants were recruited and completed the all SEBT tests for both legs in the same order. Three trials of all SEBT tests were captured by fifteen Oqus-4 infrared cameras to collect kinematic data from forty-eight spherical reflective markers attached to the foot, leg, thigh, pelvis and trunk segments using Qualisys Track Manager (QTM) (Qualisys AB, Gothenburg, Sweden) recorded at 480Hz. The test with maximum reach was used for analysis. Joint movements were calculated as the difference from the natural upright starting position to the maximum reach position for each test. **Results:** Ankle dorsiflexion is correlated with normalized reach distance in all SEBT test (not bilaterally) during performance the classic SEBT ($r = 0.475 – 0.865$, $p < 0.05$), with exception of the lateral rotational reach. The test challenges normative ROM reference values for ankle dorsiflexion in the anterior reaches and internal knee rotation in the medial rotations. Knee and hip flexion was consistently found throughout the test, except for knee extension in left L90 and right R90 reach. The stepwise regression analysis resulted in predictive movement equations for all reach directions and rotations, except for the left L90 reach. **Conclusions:** SEBT challenges normative ROM reference values for ankle dorsiflexion and knee internal knee rotation. The results from the predictive models of joint movements to reach distance were inconclusive due to side differences and a small sample size. Rotational reaches do not elicit hip transverse plane joint movements within ROM reference values.

Key Words: lower extremity, joint mobility, range of motion, balance, dynamic postural control, Star Excursion Balance Test

Table of contents

Abbreviations

A0	Anterior Reach Direction
ACL	Anterior Cruciate Ligament
ACLD	Anterior Cruciate Ligament Deficiency
ACLR	Anterior Cruciate Ligament Reconstruction
ASIS	Anterior Superior Iliac Spine
CAI	Chronic Ankle Instability
CFP	Center of Pressure
CI	Confidence Interval
EMG	Electromyography
GCS	Global Coordinate System
HJC	Hip Joint Center
ICC	Interclass Correlation Coefficient
ISB	International Society of Biomechanics
L135	Left 135° Reach Direction
L45	Left 45° Reach Direction
L90	Left 90° Reach Direction
LAS	Lateral Ankle Sprain

LCS	Local Coordinate System
LROT	Left Rotation
MVIC	Maximum Voluntary Isometric Contraction
NRD	Normalized Reach Direction
P180	Posterior Reach Direction
PFPS	Patellofemoral Pain Syndrome
QTM	Qualisys Track Manager
R135	Right 135° Reach Direction
R45	Right 45° Reach Direction
R90	Right 90° Reach Direction
ROM	Range of Motion
RROT	Right Rotation
SD	Standard Deviation
SEBT	Star Excursion Balance Test
VIF	Variance Influence Factor
YBT	Y-Balance Test

1. Introduction

Athletic and functional performance is dependent on joint movement in different planes of motion and directions. *Joint mobility* is defined as the “function of the range and ease of movement of one joint” (World Health Organization, 2001) and quantified as *Range of motion* (ROM) with normative data for different populations (Greene & Heckman, 1994; Soucie, et al., 2011; Macedo & Magee, 2009). Traditional procedures of obtaining ROM measurements of the lower extremity joints is uniplanar and unidirectional in supine, prone or seated positions with a goniometer in an open kinetic chain (Greene & Heckman, 1994). However, most functional and athletic tasks are combinations of open and closed chain activities with interactions of multiple joints, planes of motion and directions. The open chain goniometric measurements represent the available joint movement in one plane of motion in one direction, thus lacking this specificity to many functional and athletic tasks. Additionally, most functional and athletic tasks of the lower extremities do not challenge these normative data, and is therefore incomparable to traditional goniometric measurements.

Open and closed chain approach to testing joint movement will reflect different qualities, such as strength, soft tissue tension, joint mobility, balance and dynamic postural control. Traditional active and passive goniometric assessment of joint ROM will primarily reflect passive soft tissue tension and stretch tolerance (Magnusson, 1998), whereas closed kinetic chain approach to joint movement testing will reflect strength, balance and dynamic postural control and thus be representative of the available functional joint movement. Closed kinetic chain task or activities require a certain level of strength with task specific muscle activation patterns (Norris & Trudelle-Jackson, 2011; Eriksrud & Bohannon, 2003; Begalle, DiStefano, Blackburn, & Padua, 2012; Gribble, Hertle, & Denegar, 2007), in addition to balance and dynamic postural control. Balance is the ability to maintain the center of gravity’s projection within the base of support when standing and during movement whereas dynamic postural control is the ability to prevent loss of balance (Shumway-Cook & Woollacott, 2012). Consequently, lower extremity joint movements elicited in standing closed kinetic chain activities, functional joint mobility, might offer a better representation of the joint movements available to different athletic and functional tasks than goniometric measurements. Thus, a systematic task based approach to testing functional joint mobility which integrate strength, balance and dynamic postural control is beneficial. This will provide the trainer or clinician with information not captured by goniometric measurements.

Human movement is based on task, environment and individual (Shumway-Cook & Woollacott, 2012). The Star Excursion Balance Test (SEBT) account for these factors in that it challenges the *individual* within a controlled *environment* with a *task* of reaching as far as possible with one foot, thus evaluating functional joint mobility of the stance foot (Gribble P. A., 2003). SEBT was first described as a clinical treatment tool by Gary Gray (Gray, 1995). Since then it has been implemented as a measure of dynamic postural control and used as a diagnostic tool to detect risks of injury, to differentiate pathological conditions and evaluate the outcome of different interventions (Gribble, Hertle, & Plisky, 2012). The SEBT consist of a total of 16 unilateral squats (8 for each leg) where the non-stance foot reaches as far as possible along eight horizontal lines at 45° intervals, all of which comes from a center point defining a grid where the stance foot is centered (Gribble P. A., 2003). The reach has to be performed in a controlled manner and the reaching foot is allowed to gently touch the line of the reaching direction at maximum reach position before returning to an upright position. The heel, big and little toe of the stance foot is to maintain contact with the floor throughout the reach. Each test is named based on reach direction in reference to stance foot (Gribble, Hertle, & Plisky, 2012). The stance leg functions in a closed kinetic chain with the ankle, knee and hip movements dependent on each other in solving or configuring themselves to solve the reach of the other foot in a specific direction. The center of pressure will move within the base of support of the stance foot, thus challenging balance and dynamic postural control.

The SEBT is time consuming in the clinical or athletic environment since it consists of 16 different tests. Thus, the Y Balance Test (YBT), an abbreviated version of the SEBT, was developed with the aim to reduce the time taken to perform the test without loss of investigative properties on dynamic postural control. Hertel and coworkers (2006) used factor analysis on reach performance from the SEBT in an effort to reduce the reach directions necessary to detect chronic ankle instability (CAI). They found that the posteromedial reach direction captures the least redundant information (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). Then, Plisky and coworkers (2006) found an increased susceptibility of lower extremity injury using the anterior reach direction, while not in the posterolateral or posteromedial reach direction (Plisky, Rauh, Kaminski, & Underwood, 2006). Although the idea of reducing the reach directions based on time requirements and to capture the least redundant information is excellent, there is limited evidence as to why the posterolateral reach direction is part of the YBT, as it was defined by Coughlan and coworkers (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012).

Plisky and coworkers (2006) speculated that it is nearly impossible for one examiner to evaluate stance leg movement quality while simultaneously marking reach distance and secure correct stance foot heel-touch throughout the movement (Plisky, Rauh, Kaminski, & Underwood, 2006). Consequently, a study by Coughlan and coworkers (2012) used a commercially available device (Move2Perform, Evansville, IN) to evaluate reach distance during the YBT, which automatically measures reach distance. The subjects are positioned with the stance leg on an elevated central footplate while pushing a sliding block down the reach directions. The authors found a statistically significant difference between the YBT and SEBT for the anterior reach only, and presented the reasons for the difference being the mechanism of feedback from the visual system from the sliding block. The maximum reach direction was established as the mean of three reaches. No motion analysis controlled for differences in joint kinematics during the execution of the SEBT and the YBT, however, the device has been shown to have good intra-rater and inter-rater reliability (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012; Plisky, et al., 2009). Only the posteromedial reach direction has been shown to give the least redundant information, and the anterior reach direction has the most significant value to predict lower extremity injury in one study (Hertel, Braham, Hale, & Olmsted-Kramer, 2006; Plisky, Rauh, Kaminski, & Underwood, 2006). The posterolateral reach direction has no indications why it should be represented more than any other reach direction: Plisky and coworkers (2006) did not argue as to why they chose the posterolateral as one of the three, and not any other reach directions. Therefore, although the idea of reducing the reach directions based on time requirements and to capture the least redundant information is excellent, further studies with is warranted to deduce the optimal number and directions of the SEBT.

The evaluation of the performance of the SEBT is both qualitative and quantitative. The reach distance in centimeters is the primary outcome measure of the SEBT for research and clinical application. This parameter is normalized to leg length in order to compare between individuals (Gribble & Hertle, 2003). Both normalized (%) and absolute (cm) reach distance has several beneficial purposes: 1) generate normative data, which will allow for rating and ranking for statistical means, 2) monitor effect of interventions, and 3) identify risk of injury (Gribble, Hertle, & Plisky, 2012). Normalization also eliminates reach distance differences between male and females (Gribble & Hertle, 2003). The qualitative assessment of the SEBT is used clinically to assess alignment of hip, knee and foot while performing reaches (Gribble, Hertle, & Plisky, 2012). Ness and coworkers (2015) evaluated the ability to evaluate frontal movement quality during performance in the anterior reach among three independent physical therapists, and found promising results (Ness, Taylor, Haberl, Reuteman, & Borgert, 2015).

1.1 SEBT Reliability

The earliest known attempt to assess the reliability of the SEBT was done by Kinzey and coworkers (Kinzey & Armstrong, 1998). They calculated reliability of the reach distances among twenty subjects, nine males and eleven females. The four diagonal reaches: anteromedial, anterolateral, posteromedial and posterolateral, where analyzed in this study. However, when reaching to the right, the subject used the right foot and when reaching to the left they used the left foot. Thus, they only estimated reliability of two SEBT reach directions/tests. The authors found the interclass correlation coefficient (ICC) to range from 0.67 to 0.87 (Kinzey & Armstrong, 1998). A study by Gribble, Kelly, Refushauge, & Hiller (2013) reported high interrater reliability for the SEBT with an interclass correlation coefficient (ICC (1.1)) ranging from 0.86 to 0.92. However, this was only for the anterior, posteromedial and posterolateral (YBT) reach directions and only on for on leg (Gribble, Kelly, Refushauge, & Hiller, 2013). Using the Y-balance Test kit™, Plisky et al. (2009) found similar results, with an ICC for intra- and interrater reliability ranging from 0.85 to 0.91 and 0.99 to 1.00 respectively (Plisky, et al., 2009). In this study, the subjects used athletic shoes on the stance leg and were allowed to use their arms for counterbalance while moving, which might make comparisons to other studies difficult. The use of athletic shoes enhance balance compared to barefoot, with the subsequent possibility of an increased reach distance (Smith, et al., 2015) Additionally, it is more difficult for the tester to control for maintenance of correct foot placement. Another study reported relatively high ICCs of the intertester reliability of the full SEBT, ranging from 0.78 to 0.96 (Hertel, Miller, & Denegar, 2000). Their protocol consisted of testing the same participants twice on consecutive days with different examiners. However, the participants were allowed to move their arms and wear athletic shoes, which is not according procedures as described by Gribble (Gribble P. A., 2003). On the first day, the ICC ranged from 0.35 to 0.84 and on the second day, the ICC ranged from 0.81 to 0.92. Based on the following criteria for ICC, a value of 0.60 to 0.75 is considered good and ICC > 0.75 is considered excellent (Fleiss, 1981). The SEBT and YBT have good to excellent inter- and intrarater reliability. However, reliability for the full SEBT tests, as described by Gribble (2003), has not been established.

1.2 Muscle activity during SEBT

To the authors knowledge, there is only two studies investigating different muscular recruitment patterns as well as level of activation of different muscles (Norris & Trudelle-Jackson, 2011; Earl & Hertel, 2001). Norris & Trudelle-Jackson (2011) used surface EMG to quantify hip- and thigh-muscle activation during anterior, medial and posteromedial foot reaches and compared muscle activity to maximal voluntary isometric contraction (MVIC) (Norris & Trudelle-Jackson, 2011). The EMG activity of the gluteus medius muscle was highest in the medial reach direction (48 % of MVIC), while the gluteus maximus had a consistent EMG activity of 21-25 % of MVIC for all reach directions. Similarly, the vastus medialis muscle also had consistent EMG activity across all reach directions at 69 – 77 % of MVIC. Only the dominant stance foot was measured. Another study also measured EMG activity for the full SEBT to determine if there were significant differences in muscle activation between tests (Earl & Hertel, 2001). The researchers measured activity in the anterior tibialis, gastrocnemius, vastus medialis, vastus lateralis, medial hamstring and biceps femoris. Vastus medialis muscle activity was found be greatest in the anterior direction and lowest in the lateral and anterolateral direction. Vastus lateralis activity was consistent in all reach directions, except for the lateral reach, where it was significantly lower. The medial hamstring EMG activity during the anterolateral reach direction was significantly higher than its activity in the anterolateral, anteromedial and medial reach direction. The biceps femoris showed the highest activity in the posterior, posterolateral and the lateral reach, which were significantly higher than in the anterior and anteromedial reach direction.

The anterior tibialis muscle activity was significantly higher in the posterior reaches than in the anterior reaches and the gastrocnemius activity was consistent throughout all reach directions (Earl & Hertel, 2001). Based on the results from the two studies, it seems that the activity of the lower extremity muscles is reach dependent. A weakness of the study by Earl and Hertel (2001) consisted of the subjects not fixating their arms to their pelvic region. The free arm movement reduces the challenge of balancing by increasing the counterweight moment during reaching and subsequently altering muscle functions. These studies indicate that different SEBT tests recruit muscles differently.

1.3 SEBT and Injuries

The SEBT has been found to be sensitive and able to different lower extremity musculoskeletal dysfunctions and injuries such as CAI, anterior cruciate ligament (ACL) injuries and patellofemoral pain syndrome (PFPS) (Gribble, Hertle, & Plisky, 2012).

1.3.1 Chronic ankle instability

Lateral ankle sprain has for a long time been one of the most common injuries in sports (Garrick, 1977; Ferran, N, & Maffulli, 2006; Attenborough, et al., 2014). Olmsted and coworkers (2002) found a significant side-by-group difference ($F_{1,38} = 3.99$, $p = .05$) between subjects with CAI and healthy control group: while standing on the injured leg, the CAI group reached an average of 78.6 cm while the control group reached 82.8 cm. Additionally, they also found a side-to-side difference within the CAI group: 78.6 cm vs. 81.2 cm on the injured vs. uninjured stance leg, respectively ($p<.05$) (Olmsted, Carcia, Hertel, & Schultz, 2002). One weakness with the study by Olmsted and coworkers (2002) is the absence of normalization of reach distance. The CAI groups height was on average 2 cm lower than the control group. Consequently, leg length could be a confounding factor to their results. A two-dimensional video analysis evaluated reach distance sagittal kinematics in the ankle, knee and hip during performance of the YBT in subjects diagnosed with lateral ankle sprain (LAS) compared to healthy subjects (Doherty, et al., 2015a). They found a significant reduction in reach distance between the control and the LAS group for both affected and unaffected stance leg in all directions (anterior: $p = .007$; posterolateral: $p < .001$; posteromedial: $p = .005$). They found no difference in ankle dorsiflexion ROM between the control and LAS group for either leg using the knee-to-wall test. However, they found a significant reduction of ankle dorsiflexion in the LAS group compared with the control group in anterior and posteromedial reach direction, with p = .02 and p = .01, respectively. In addition, a significant reduction in hip and knee motion in the sagittal plane for the LAS group compared with the control group was found (Doherty, et al., 2015a). Because the ankle dorsiflexion ROM was the same for the two groups using the knee-to-wall test, but different during the SEBT, the authors speculate that a motor control compensatory movement in other planes of motion were more utilized in the control group, resulting in improved reach distance (Doherty, et al., 2015a). However, this is difficult to verify without at least a full lower extremity three-dimensional kinematic analysis. Olmsted and coworkers (2002) investigated the difference of reach direction between a group of healthy, athletic population (20 participants, 10 males and 10 females) and a group of 20 participants with unilateral CAI (10 males and 10 females). The CAI diagnose was set by the following criteria: at least one episode of lateral ankle sprain and multiple episode of the ankle "giving away" within the last twelve months, which is the diagnostic criteria for CAI (Attenborough, et al., 2014). Both groups in the study by Olmsted and coworkers (2002) used all directions of the SEBT for both limbs. They found a reduced reach distance in all reach directions between the CAI group compared to the uninjured group when matched by the same side limb and a reduced reach distance between injured and uninjured limbs within the CAI group (p = .05 for both results). However, the authors of the study did not normalize the reach distance to leg length, as suggested by Gribble & Hertel (2003) (Olmsted, Carcia, Hertel, & Schultz, 2002; Gribble & Hertle, 2003). The leg length of the CAI group (93.71 ± 7.1 cm) and for the healthy, athletic population (95.5 ± 5.2 cm) could be a confounding factor to differences in the reach distance. Additionally, no joint kinematics was measured and the dominant limb was not established, leaving the interpretation of the results difficult. The study by Akbari and colleagues (2006) investigated the difference in reach distance for CAI limb and uninjured limb. Although they found a significant difference between subjects, p <.05, they did not report which reach directions they used (Akbari, Karimi, Farahini, & Faghihzadeh, 2006).

A study by de la Motte (2015) investigated if CAI had a direction specific deficit in reach distance, using a motion capture system. CAI was determined by criteria previously described, and the healthy group was matched to the CAI group based on sex, height, weight and dominant limb. They tested three reach directions of the SEBT:

anteromedial, medial and posteromedial. Maximum joint excursion was calculated as the difference in joint position from a frame in the starting position to the frame of the maximum reach position. The frame when the reach foot marker was furthest away from the body was visually verified as the maximum reach distance in their motion capture software. An event marker was set, and kinematic values was extracted from this spatiotemporal point. For statistical analysis, they used the mean distance of all six repetitions for each reach direction. In contrast to the previous mentioned studies investigating reach distance differences between subjects with CAI and healthy subjects, de la Motte et al. (2015) found no significant difference between reach distances (anteromedial: t = 0.44, p = .66; medial: t = 0.94, p = .35; posteromedial: t = 0.76, p = .45). However, they found significant differences between the CAI group and the uninjured group in the kinematic analysis. For the anteromedial reach, trunk lateral rotation (mean difference = 26.59°, 95% CI = 9.02, 44.16, p = .004) and hip flexion (mean difference = -12.95°, 95% CI = -23.90, -2.01, p = .02) was greater in the CAI group. For the medial reach, trunk flexion was greater in the CAI group (21.61° versus 14.82°, p = .05), although the mean difference 95% CI crosses zero (95% CI = -13.59, 0.01). For the posteromedial reach direction, no significant differences were found. In addition, no significant differences were found in ankle kinematics for all reach directions (de la Motte, Arnold, & Ross, 2015). Similarly, a study by Sefton and coworkers (2009) also investigated the effect of CAI on reach distance in SEBT for the anteromedial, medial and posteromedial directions and found no significant difference (p = .91, p = .35 and p = .14 for each reach direction, respectively). They did not investigate any kinematics during performance of the SEBT (Sefton, et al., 2009). Sefton and coworkers (2009) used the Foot and Ankle Disability Index (FEDI) as an inclusion criterion in their study. The CAI group scored 37% with standard deviations (SD) of 73.5%. The high SD could threaten the homogeneity of the CAI group. Pionnier and coworkers (2016) found significant reduction in ankle and knee frontal and transversal joint movement and hip transversal joint movement in the CAI group compared to a similar control group (p < .05), using three-dimensional motion capture. They also calculated composite normalized reach distance score for all tests and found a significant reduction for the CAI group compared to the control group (79.9 % vs. 84.7%, for the CAI vs. control, p = 0.009) (Pionnier, Decoufour, Barbier, Popineau, & Simoneu-Beussinger, 2016). It appears to be strong indications to reach distance differences during performance of the SEBT between subjects with CAI and a healthy control group, although conflicting exists. Joint kinematics differences in the lower extremity elicited by the SEBT between groups is evident. Thus, the SEBT has the sensitivity to determine functional (balance and dynamic postural control) and kinematic deficits of an individual with LAS or CAI.

1.3.2 Anterior Cruciate Ligament Injuries

ACL injuries are relatively common in sports: a systematic summary of systematic reviews reported an incidence rate of 5% in female athletes in European football and basketball, with females at three times the risk of injury than men with the rate of return to competitive sports post ACL-reconstruction (ACL-R) is reported to be as low as 44% in some studies (sex not specified) (Anderson, Browning, Urband, Kluczynski, & Bisson, 2016). Subjects with anterior cruciate ligament deficiency (ACL-D) has a reduced reach distance during performance of selected reach directions of the SEBT (Herrington, Hatcher, Hatcher, & McNicholas, 2009). Herrington and coworkers (2009) used 25 subjects which were diagnosed with ACL-D and compared reach distance with a control group. The time since onset of injury varied between 5 months and 2 years (mean ± SD: 11 ± 2 months). The anterior drawer test, Lachman’s test, pivot shift and MRI or arthroscopic examination confirmed their diagnosis. The control group were matched in gender, age and general level of physical activity. With a Bonferonni corrected α-value, a difference in reach distance between the control group and the ACL-D limb was significant in the anterior, lateral, posteromedial and medial direction ($p = .0032$, $p = .005$, $p = 0024$ and $p = 001$, respectively). A cross sectional study aimed to compare the performance on the YBT between subjects with ACL-R and healthy subjects at the time of return to sport (Clagg, Paterno, Hewett, & Schmitt, 2015). They found a significant reduction of reach distance in the anterior direction for the ACL-R group compared to the healthy group ($p=.001$). They did not, however, measure or register any joint kinematics and thus unable to conclude with any specific reasons as to why they found a significant reduction in reach distance.

A major prospective cohort study by Krosshaug & coworkers (2016) investigated if five kinematic and kinetic variables during vertical drop jump are associated with future ACL injuries: (1) knee valgus angle at initial contact, (2) peak abduction torque moment, (3) peak knee flexion angle, (4) peak ground-reaction force and (5) medial knee displacement. The only factor associated with increased risk of ACL injury they found, was medial knee displacement (Krosshaug, et al., 2016). Transferability of results from vertical drop jumps to performance of the SEBT is not investigated, and should be done cautiously due to the deceleration moments produced in a vertical drop jump, which is absent in the SEBT. Medial displacement of the knee during closed kinetic chain movements is associated with hip abductor weakness, although variable among subjects (Geiser, O'Connor, & Earl, 2010). Delahunt and coworkers (2013) investigated differences in kinematics in the lower extremity and reach distance in a group of anterior cruciate ligament reconstructed (ACL-R) group vs. a control group. Supporting the findings from Krosshaug and coworkers (2016), they found an increased hip adduction in the ACL-R group compared to the control group in the anterior reach, indicating knee medial displacement and hip abductor weakness (Delahunt, et al., 2013). Furthermore, Ness and coworkers (2015) evaluated the relationship between movement quality and SEBT anterior reach outcome. While performing the anterior reach distance, three independent physical therapist evaluated knee medial displacement motion. The scoring was in a dichotomous manner, either medial displacement was present or it was absent, rating subjects with either 1 or 0, respectively. From a frontal plane perspective, knee medial displacement was present if the tibial tuberosity was medial to the second toe during performance of the SEBT in the anterior direction. For the knee assessment, they found a moderately strong specificity (0.59 – 0.82) and poor sensitivity (0.14 – 0.39) (Ness, Taylor, Haberl, Reuteman, & Borgert, 2015). Deficits in dynamic postural control and concomitant altered hip- and knee-joint kinematics are present after an ACL injury, be it deficiency or reconstruction (Anderson, Browning, Urband, Kluczynski, & Bisson, 2016). It seems that the SEBT is able to differentiate between healthy people and those with an increased risk of ACL injuries, especially during performance of the anterior reach by visually investigating global knee movement, and not knee motion in itself. Additionally, because of the knee medial displacement association with ACL injury, the SEBT would be an excellent evaluation test concerning return to sport subsequent to ACL injuries.

1.3.3 Patellofemoral pain syndrome

A common musculoskeletal dysfunction of the lower extremity is patellofemoral pain syndrome (PFPS), which has been found to account for a substantial percentage (40%) of all knee injuries (Rothermich, Glaviano, Li, & Hart, 2015). Subjects with patellofemoral pain syndrome (PFPS) have been found to have a reduced SEBT anterior reach distance. Animaka & Gribble (2008) found a significant reduction in normalized reach distance in the anterior direction between subjects with PFPS and healthy control subjects, 63.5% ± 1.3 % vs. 65.6% ± 1.2 respectively (Animaka & Gribble, 2008). These findings have been corroborated where YBT reach distance is associated with risk of lower extremity injury in high school basketball players. Of all the reach directions, they found a significant correlation with the performance of the YBT and risk of lower extremity injury (Plisky, Rauh, Kaminski, & Underwood, 2006). In addition to PFPS, this study included other lower extremity injuries such as any injury to the hip, knee and ankle, thus including ACLD/RLAS and CAI. The study by Animaka and Gribble (2008) is the only know study that specifically investigates the effect of PFPS on the performance of the SEBT.

1.4 Kinematic predictions of SEBT reach distance

The SEBT elicits movement in all joints of the lower extremity in all planes of motion. Studies has described ankle, knee, hip, pelvic and trunk kinematics during the performance of the SEBT, with some conflicting results.

1.4.1 Ankle Kinematics

Ankle sagittal motion has been extensively researched while performing the SEBT. Gribble and coworkers (2007) investigated sagittal kinematics in the lower extremity and reach distance difference in a CAI-group and a control group. Results from their stepwise regression analysis indicated that a reduction of sagittal motion in the hip and knee following a fatigue protocol explains a reduction of reach distance during the SEBT. Additionally, in the anterior and the medial direction, CAI also contributed to the explained variance. They did not present any kinematic data and they did not report any significant ankle motion during performance of the anterior, medial and posterior reaches (Gribble, Hertle, & Denegar, 2007). However, another study showed a strong correlation of ankle dorsiflexion and SEBT reach in the anterior direction (Hoch, Staton, & McKeon, 2011). They used weight bearing lunge tests to estimate maximal ankle dorsiflexion and then compared the results with YBT. Of these three directions, the anterior direction had the strongest correlation with dorsiflexion, which accounted for 28% of the predicted reach distance (p=0.001). They also did not present any raw kinematic data for the ankle. A study by Kang and coworkers (2015) investigated kinematic predictors of reach distance in the YBT in the ankle, knee, and hip joint as well as trunk and pelvic (which were both calculated as the absolute motions of each segment from the laboratory coordinate system) motion in the sagittal, transverse and frontal plane using 3D motion analysis. Using stepwise multiple regression, ankle dorsiflexion was the best single predictor of normalized reach distance in the anterior direction. They also reported a maximum ankle sagittal ROM of 39.26° ± 5.34° in the anterior direction, frontal ROM of 7.07° ± 1.90° (inversion) in the posterolateral direction and transversal ROM of 25.66° ± 4.51° (external rotation), also in the posterolateral direction (Kang, Kim, Weon, Oh, & An, 2015). Fullam and coworkers (2014) reported their greatest ankle sagittal ROM of 32.60° ± 6.20° when using the YBT Move2Perform test device, and 30.96° ± 7.22° when performing the classic SEBT, both in the anterior reach direction, although not significant to reach distance (Fullam, Caulfield, Coughlan, & Delahunt, 2014). They only investigated sagittal motion in the ankle, knee and hip in the anterior direction. In 2015, de la Motte and coworkers investigated 3D kinematics of the ankle, knee, hip and trunk during performance of the anteromedial, medial and the posteromedial reach using full 3D motion capture system (de la Motte, Arnold, & Ross, 2015). They reported a maximum ankle dorsiflexion ROM of 41.00° ± 8.48° and maximum external rotation ROM of 20.60° ± 14.02° in the anteromedial direction and maximum ankle inversion ROM of 6.01° ± 5.36° in the posteromedial direction in the group with healthy subjects. Their standard deviation for ankle dorsiflexion within the CAI group is almost equal to their dorsiflexion joint excursion, indicating an extreme variability of ankle dorsiflexion among this group. No ankle motion was considered significant to reach distance for any reach direction in their study. It appears that the anterior movements of the SEBT elicits the greatest ankle motions, and the greatest dorsiflexion is greater than the normative value considering classic goniometrical measured ROM of 12° - 20° (Macedo & Magee, 2009; Soucie, et al., 2011; Greene & Heckman, 1994)

1.4.2 Knee Kinematics

A study by Robinson and Gribble (2008b) investigated the kinematic predictors of reach distance during performance of the SEBT. Ten female and male subjects performed all reach directions of the SEBT while the authors recorded three-dimensional hip joint movement and sagittal plane knee movement. Backwards stepwise multiple regression analysis of each reach directions with the normalized reach distance as the dependent variable, and the joint excursions as the predictor variables was employed to predict reach distance based upon hip and knee joint movement. With hip flexion combined with knee flexion, the reach distance was predicted by 78-88% during performance of the anterior and lateral reach directions, with the greatest knee flexion ROM reported in the medial direction (55.87° ± 22.30°) (Robinson & Gribble, 2008b). The authors only measured knee sagittal motion and hip motion in all planes without measuring ankle motions or the secondary planes of motion of the knee. When maintaining balance in a closed kinetic chain, the ankle goes into dorsiflexion when the proximal part of tibia moves forward, forcing the knee into flexion (Baumbach, et al., 2014; Hoch, Staton, & McKeon, 2011). This may overestimate the relative strong predicting results by hip and knee flexion presented by Robinson and Gribble (2008b), by not considering ankle motion in the equation. Fullam and coworkers (2014) reported a maximum knee flexion of 59.59° ± 13.05° in the anterior direction using the YBT device, and 53.97° ± 15.54° during the classic SEBT in the same direction (Fullam, Caulfield, Coughlan, & Delahunt, 2014). De la Motte and coworkers (2015) reported their greatest knee flexion of 50.11° ± 13.85°, knee abduction of 24.45° ± 11.45° and knee external rotation of 10.51° ± 14.88°, all in the anteromedial reach direction. However, they did not test the anterior direction (de la Motte, Arnold, & Ross, 2015). Testing the YBT, Kang and coworkers (2015) reported their greatest knee flexion of 68.87° ± 9.63° and knee internal rotation of 26.64° ± 6.37° during performance in the posteromedial direction and the greatest knee adduction of 21.54° ± 9.76° was elicited by the posterolateral direction (Kang, Kim, Weon, Oh, & An, 2015). With a normative ROM reference value of 137 – 150° knee flexion (Macedo & Magee, 2009; Soucie, et al., 2011), the SEBT does not challenge maximum knee flexion, however, the range currently represented by the SEBT (50° – 68°) is within the ideal angle of torque production considering quadriceps muscle moment arm, fascicle length and intra-muscle coactivation (Trezise, Collier, & Blazevich, 2016), indicting an ideal working knee sagittal position. Thus, it appears that strength, and not knee ROM, is predictive of reach distance during performance of the SEBT.

1.4.3 Hip Kinematics

Robinson and Gribble (2008b) found significant regression models for all reach directions, concluding that knee and hip joint excursion, both singular and in combination predicted normalized reach distance in all directions (range: $R^2 = 0.95$ to $R^2 = 0.662$, $p<.001$). They found that hip flexion by itself accounted for 86-95% of the kinematic variance in the anterior, posterior, posterolateral and posteromedial directions (Robinson & Gribble, 2008b). However, as mentioned earlier, they did not measure ankle motion, which can be a confounding factor. Using a 3D motion capture system, de la Motte and coworkers (2015) calculated maximum joint excursion between healthy subjects and subjects with CAI. For the anteromedial reach, hip flexion was significantly greater for the CAI group (36° vs. 23° for the CAI and healthy subjects, respectively, p = .002), however, their greatest hip flexion of 69.81° ± 22.67° was elicited by the posteromedial reach for the subjects with CAI while the hip flexion ROM was 66.23° ± 17.32° in the control group (de la Motte, Arnold, & Ross, 2015). Using stepwise multiple regression, Kang and coworkers (2015) found that hip flexion was the best single predictors of normalized reach distance in the posterior reach directions, with hip flexion values of 73° and 77° in the posteromedial and posterolateral direction, respectively. Their maximum hip abduction of 9.12° ± 5.95° was elicited by the posteromedial direction, and the greatest internal rotation was elicited by the anterior reach direction (Kang, Kim, Weon, Oh, & An, 2015). In the anterior direction, Fullam and coworkers (2014) reported a significant difference of maximum hip flexion between the YBT and the classic SEBT, with 28.32° ± 13.19° vs. 20.37° ± 18.63°, respectively. They also found a positive correlation between hip flexion and performance of the YBT and a negative correlation between hip flexion and performance of the classic SEBT, indicating an inversely proportional relationship between hip flexion and SEBT performance in this direction. However, their negative correlation value is -0.06, which is weak and indicates that there is no relationship between the two variables (Cohen, 1988). They did not measure any frontal or transverse motions in either joint, and although the anterior reach could be viewed as a single plane motion, multiple studies has shown that this reach direction elicits multiplanar joint movements throughout the lower extremity (Robinson & Gribble, 2008b; Ness, Taylor, Haberl, Reuteman, & Borgert, 2015; Kang, Kim, Weon, Oh, & An, 2015). With a hip flexion normative reference value of 120° – 130° (Greene & Heckman, 1994; Soucie, et al., 2011), none of the results in current studies challenges sagittal hip ROM. However, the maximum hip flexion angle currently elicited by SEBT appears to be within the ideal torque producing range of 50° – 70° of flexion (Levangie & Norkin, 2011). Concurrent with ideal knee flexion angle for torque production as mentioned earlier, the SEBTs posterior reaches performance appears to be determined by the ability for ideal torque production by the hip and knee, thus strength, and not joint movements, determining reach differences.

The current protocol of the SEBT evaluates joint movement when reaching down lines in fixated angles relative to the starting position. Although transversal joint movements are elicited in these reaches, the human ability of horizontal rotations during single leg stance during the SEBT is not challenged. Traditional investigation of transverse joint movement of the knee and hip is usually performed in lying or seated position in an open chain (Greene & Heckman, 1994). For a more thorough understanding of human movement, one has to investigate the kinematic solutions of the lower extremity during the limits of rotation in a closed kinetic chain. Concurrent with the classic SEBT, it is hypothesized that rotational reaches will elicit a functional representation of transverse joint movements which is task specific to athletic and functional movements.

1.5 Summary

No previous studies have investigated lower extremity three-dimensional kinematics for all SEBT tests. In addition, the current SEBT does not challenge rotational movements in the lower extremity, especially the hip. Therefore, the purpose of this study is to 1) perform a kinematic three-dimensional analysis of lower extremity joints and the trunk for all SEBT test, 2) compare joint motion elicited by the SEBT with normative ROM reference values, 3) establish joint movement predictors of reach performance of the different SEBT tests and 4) introduce two new rotational tests for evaluation of transverse joint movements.

2. Methods

A cross sectional study using quantitative analysis was applied for research purposes.

2.1 Subjects

Twenty male participants (age: 24.4 ± 2.3 years; height: 181.3 ± 6.0 cm; weight: 77.7 ± 11.8 kg) were recruited for the study.

Exclusion criteria were:

- Female
- Under the age of 18
- History of neuromuscular injuries or disease
- Injuries restricting movement
- Musculoskeletal injuries in the past six months

The Regional Ethics committee approved the study and The Norwegian Data Protection Authority approved storage of personal data. All subjects were informed about the purpose of the study, as well as the advantages and risks of participating, after which an informed consent was signed (Appendix). Participation was voluntary, and the subjects were informed that they could withdraw from the study at any time without any consequences.

2.2 Setup

All testing was carried out in the Human Movement and Biomechanics Lab of the Norwegian School of Sport Sciences.

Fifteen Oqus-4 infrared cameras (ProReflex®, Qualisys Inc., Gothenburg, Sweden) were used to collect kinematic data using the Qualisys Track Manager (QTM) software (Qualisys AB, Gothenburg, Sweden) at 480Hz to measure joint movements during each foot reach test. The movement space was calibrated using the Qualisys calibration kit consisting of a 750 mm T-shaped stick with two reflective markers at each tip of the T-bar and a stationary L-shaped bar with four reflective markers (of known distances placed in the corner, one on each end and one in the middle of the long part). The L-shaped stick indicated the direction of the global coordination system, and the T-shape indicated the movement space for the participants. After the calibration, the cameras covered an approximate recording area of nine cubic meters (3m x 3m x 3m).

Forty-eight spherical reflective markers (20mm Ø) were attached to specific anatomical landmarks using bi-adhesive tape in order to define foot, leg, thigh, pelvis and trunk segments. The maker clusters used for the leg and thigh segments were attached firmly using tensoplast elastic tape (BSN Medical GmBH, Hamburg, Germany). The following anatomical locations were used: 1) foot (head of the first (FM1) and fifth (MVH) metatarsal, midpoint posterior calcaneus (CAL)), 2) leg (medial (TAM) and lateral (FAL) malleolus, proximal and lateral cluster of four markers (SK1-4)), 3) thigh (medial (FME) and lateral (FLE) femoral epicondyle, greater trochanter (FT) middle and lateral cluster of four marker (TH1-4)., 4) pelvis, (right and lest anterior (RIAS and LIAS) and posterior (LIPS and RIPS) iliac spines and lateral iliac crest (RPEL and LPEL) and 5) thorax (spinous process of the 10th thoracic (TV10) and the seventh cervical (CV7) vertebrae, xiphisternal joint (SXS) and jugular notch (SJN)). Markers were identified using standard software.

For ease of measurement the SEBT was performed on a mat (Athletic Knowledge AB, Stockholm, Sweden) based upon the eight different directions at 45-degree intervals projecting from one central point with concentric circles at 10 cm intervals with the outer circle (90 cm radius) identifying 5° intervals. The SEBT tests have been named based on stance foot (Gribble P. A., 2003). We did not follow this definition, but based reaching directions on anatomical neutral position of the body. The anterior (A0) and posterior (P180) lines divides the grid into right (R) and left (L) halves, which are divided at 45° increments (R45, R90, R135, L135, L90 and L45). This will allow for better testing of both lower extremities on the same mat. Furthermore, the reaching directions on the mat are dotted (1 centimeter intervals) for ease of measurement.

Photos of the movement during performance of the reaches is presented in the result section in Figure 3.1.1 & Figure 3.1.2. The rotational reaches are also presented with photos, in Figure 3.2.2 & Figure 3.2.1, also in the result section.

2.3 Test Protocol

All subjects performed the testing protocol in the following order: (1) anthropometric measurement, (2) side dominance testing and (3) the SEBT protocol. No warm-up protocol was used.

2.3.1 Anthropometric measurements

Both height and weight was obtained using Seca model 217 stadiometer and a Seca flat scale (Seca GmbH. & Co. Hamburg. Germany). Leg length was measured from the greater trochanter to the floor using a standard tape measure.

2.3.2 Side dominance

Leg dominance was established using the following three tests for a total of nine repetitions:

1. Step-up test: The participant was asked to walk toward a step and take a step up three times. The leg used to take the step up most frequently was defined as dominant.
2. Pushed-forward test: the participant was gently pushed forward from behind three time. The leg most frequently used to correct for the perturbation by taking a step forward was defined as dominant.
3. Kick-test: the participants were asked to kick a ball at a target three times. The most frequent kicking leg was defined as dominant.

The most frequently used leg (>5) was defined as the dominant.

2.3.3 SEBT Procedure

All SEBT tests with the addition of two rotational reaches where done for each foot in the same order on the same testing mat (Table 2.3.1). All foot reaches were grouped based on the planes of motion that dominate the reach. The three groups are: (1) pure plane, (2) combined planes and (3) rotations. The pure plane reaches are A0, P180, R90 and L90, while diagonal reaches are R45, L45, R135 and L135. The new rotational reaches, left rotation (LROT) and right rotation (RROT) can also be considered pure plane reaches.

Table 2.3.1 Order of SEBT reaches.

REACH	STANCE FOOT	TEST#	PLANES OF MOTION	GLOBAL MOVEMENT PATTERN
R45	Left	1	Combined	Anterior
L45	Right	5	Combined	Anterior
L135	Left	2	Combined	Posterior
R135	Right	6	Combined	Posterior
L45	Left	3	Combined	Anterior
R45	Right	7	Combined	Anterior
R135	Left	4	Combined	Posterior
L135	Right	8	Combined	Posterior
A0	Left	9	Pure	Anterior
A0	Right	15	Pure	Anterior
P180	Left	10	Pure	Posterior
P180	Right	16	Pure	Posterior
R90	Left	11	Pure	Lateral
L90	Right	17	Pure	Lateral
L90	Left	12	Pure	Medial
R90	Right	18	Pure	Medial
RROT	Left	13	Pure / Rotational	Lateral Rotational
LROT	Right	19	Pure / Rotational	Lateral Rotational
LROT	Left	14	Pure / Rotational	Medial Rotational
RROT	Right	20	Pure / Rotational	Medial Rotational

In order for a test to be valid the following criteria had to be met:

1. The measured stance foot was placed in the center of the mat, with the anteroposterior line (A0 – P180) aligned with the second toe and bisecting the heel.
2. The heel, first and fifth metatarsal head had had to maintain contact with the mat throughout the test.
3. Maximum reach distance was measured by the maximum distance of the big toe in the reaching direction. A gentle toe touch without support of the big toe was allowed.
4. Subjects had to maintain balance during the reach test
5. Both hands were placed above bilateral iliac crests and kept in this position during the test.
6. Three valid tests were recorded. All failed attempts were discarded.

7. A minimum of three warm-up repetitions were given for all tests

There new rotational reach tests had the following additional criteria:

1. The foot performing the rotational reach had to move along the arc of the 50 cm radius on the mat
2. A longitudinal line (from the second toe to a midpoint on the heel) of the reaching foot had to be angled toward the center of mat during the reach.
3. Angle of maximum rotational reach was defined as a projection of the big toe along a line parallel to the longitudinal line of the foot onto the outer concentric circle of the mat.

Five testers observed the testing to ensure that the above criteria were followed. One tester controlled the data registration on QTM, two testers controlled that the reach criteria were followed, one tester observed the reach distance while one logged reach distance.

2.4 Kinematic model definitions

Prior to performing foot reaches, a five-second static calibration trial in a standardized neutral standing position was obtained: standing with legs shoulder-width apart, elbows flexed to 90° and forearms fully supinated. To secure the calibration trial and motion trial concordance, a felt pen was used to mark the location of each marker on the subjects' skin. Thus, if a marker fell off during testing, the marked location indicated the area of re-attachment and a subsequent new calibration trail was performed.

The Global coordinate system (GCS), as defined by the International Society of Biomechanics (ISB), consists of the X-axis in the anterior direction, Y-axis in cranial direction and the Z-axis in the lateral direction (Robertson, Caldwell, Hamill, Kamen, & Whittlesy, 2014). Local coordinate systems (LCS) for the thorax, pelvis, thigh, shank and foot were created from the static calibration trial based upon the recommendations by the ISB (Wu, 2002).

2.4.1 Local Coordinate System of the ankle joint complex segment

We used the same marker setup as recommended by Ge Wu in his letter to the Journal of Biomechanics, who suggested a standard for a joint coordinate system for the ankle complex to the ISB (Wu, 2002). Reflective markers are attached on the medial and lateral malleoli and on the first and fifth metatarsal heads and one on the calcaneus. The origin of the foot segment LCS is the calcaneal marker. The LCS y-axis was calculated as the projected line from the calcaneal marker to a toe marker calculated as the midpoint between the two metatarsal markers, pointing anteriorly. The ankle joint center is the midpoint between the markers on the malleoli, and the cross product of the unit vector in the sagittal plane and the y-axis indicates the x-axis pointing to the right. The cross product between the y-axis and the x-axis defines the z-axis, pointing cranially (Robertson, Caldwell, Hamill, Kamen, & Whittlesy, 2014).

2.4.2 Local Coordinate System of the shank segment

For knee motion analysis, the LCS was calculated as following, based on equations from Grood & Suntay (1983): the LCS is calculated with the position of four markers: the ones on the femoral epicondyles and the ones on the malleoli. The origin of the LCS is defined by the midpoint between the two reflective markers on the femoral epicondyles. The z-axis is the extrapolation of the projected line from the midpoint of the two malleoli markers on the calculated origin, thus pointing cranially. The y-axis is the cross product of the unit vector from the medial to lateral femoral epicondyle and the z-axis, pointing anteriorly. Finally, the x-axis is the cross product of the y-axis and the z-axis, pointing to the right (Robertson, Caldwell, Hamill, Kamen, & Whittlesy, 2014; Grood & Suntay, 1983).

2.4.3 Local Coordinate System of the Thigh Segment

In our study, the LCS for the hip is based on recommendations by Wu (2002) and the origin of the thigh segment is the hip joint center (HJC), which is calculated based on equations from Bell and coworkers (Bell, Pedersen, & Brand, 1989; Wu, 2002). The z-axis is the line between the hip joint center and the midpoint on the line between the reflective markers on the medial and lateral femoral epicondyles. The y-axis was then defined as the cross product of a lateral unit vector in the frontal plane and the unit vector along the z-axis. Finally, the cross product of the unit vectors of the y- and x-axis determined the x-axis.

2.4.4 Local Coordinate System of the Pelvis

Bell, Brand and Pedersen (1989) investigated two methods for estimating HJC (Bell, Pedersen, & Brand, 1989). The first method, devised from Tylkowski and coworkers (1982), expressed the location of the HJC as a constant percentage of the distance between the left and right anterior superior iliac spines (ASIS) using x-ray pictures of children (Tylkowski, Simon, & Mansour, 1982). The other method, devised from Andriacchi and coworker (1983), predicted the HJC at 1.5 – 2 cm distal to the midpoint between ASIS and the pubic symphysis and an unspecified distance medial to the greater trochanter (Andriacchi & Strickland, 1983). Bell and Coworkers (1982) combined the two methods for a more accurate estimation of HJC: Andriacchi's method in the frontal planed combined with Tylkowski's posterior percentage predicted the HJC to within 2.6 cm of the true location with a certainty of 95%. In our study, the HJC is calculated based upon the equations by Bell and coworkers (Bell, Pedersen, & Brand, 1989). The origin of the pelvis was defined as the midpoint of the line between the marker on the right iliac spine and the left iliac spine with the x-axis pointing to the right (Wu, 2002). The z-axis is subsequently defined as the cross product of the anterior unit vector in the transverse plane and the x-axis. The cross product of the x-axis and the z-axis determined the y-axis, projecting from the calculated origin of the pelvis and pointing cranially (Wu, 2002; Leardini, Biagi, Merlo, Belvedere, & Benedetti, 2011).

2.4.5 Local Coordinate System of the Thorax

The origin of the thorax was calculated as the midpoint between the reflective marker on tenth thoracic spinous process and the reflective marker on the xiphisternal joint. The projected line from this midpoint to the midpoint between the reflective marker on the jugular notch and seventh cervical spinous process indicated the z-axis, pointing cranially. Pointing anterior, the y-axis is the projected line from the origin toward the reflective marker on the xiphisternal joint. The cross product of the unit vectors of y- and z-axis defines the x-axis (Wu, 2002; Leardini, Biagi, Merlo, Belvedere, & Benedetti, 2011)

2.4.6 Kinematic model

Joint rotations of the *ankle* (foot and leg segment), *knee* (leg and thigh segment), *hip* (thigh and pelvic segment) and *spine* (pelvic and thoracic segment) were calculated (cardan sequence XYZ) in the sagittal (X-axis), frontal (Y-axis), and transverse (Z-axis) planes.

2.5 Data analysis

Markers were identified using standard software QTM. If reflective markers were lost during motion capturing, manually gap filling corrected the missing parts using the *gap fill trajectory* option in QTM. Depending on the presented preview by QTM, either a polynomial or linear trajectory was selected. If the missing part were excessive or the gap filling function in QTM presented abnormal values based on visual inspection the gap was left unfilled.

In Visual 3D (C-Motion, Research Biomechanics, US), a workspace pipeline was set for each test that included adding a premade model for Visual3Ds marker recognition with definitions of the local coordinate systems as described above. A secondary pipeline contained coding to map the individual body segments. Specifically, data analysis was performed using Visual 3D® (C-Motion Inc., Rockville, MD, USA). The marker locations registered in the static standing trial was used to determine the static calibration of the kinematic model. Each reach test (motion file) was then added in order to determine joint movements elicited by different foot reach tests. The test with the greatest foot reach (centimeter or degrees) were used for kinematic analysis.

Three-dimensional joint movements ($\theta=\phi_{max}-\phi_{start}$) elicited by different foot reach tests were calculated from an anatomically neutral starting point ($\phi_{start}=$ mean$_{frames\ 5\text{-}100}$) and maximum reach position (ϕ_{max}) in the global coordinate system. The maximum reach position was defined to reflect the maximum foot reach scores. Specifically, three different methods were used for max joint excursion calculations: one for the A0, R/L90 and P180 reach direction, called the *pure planes*. Another for the R/L45 and R/L135 directions, called the *combined planes* and one for the *rotations* (Table 2.3.1). Position of the fifth metatarsal marker (RFM1 or LFM1) was used to define maximum reach position for all reaches (ϕ_{max}). For the *combined planes reaches*, maximum reach position (ϕ_{max}) of either RFM1 or LFM1 was calculated by the position in two dimensions in order to more precisely describe maximum reach position. In the *pure plane reaches*, only the local maximum of one coordinate was necessary. The P180 reach was established with the maximum X component while A0 the minimum X component was used for ϕ_{max}. In the lateral reaches, (L90 and R90) minimum and maximum Y components were used for ϕ_{max}. In the *rotational reaches*, the maximum Y component of the respective FM1 reflective marker were used.

Three-dimensional joint movements were then exported to and sorted in Microsoft Excel (Microsoft, US.) for further analysis in SPSS (SPSS 22.0, Chicago). Reach distance was normalized to leg length as described by Gribble and coworkers (Gribble & Hertle, 2003). The following joint movements were analyzed for each reach direction: standing ankle and knee joints, bilateral hip joints and spine.

2.6 Statistics

Mean and standard deviation for joint excursion at maximal reach was calculated in Excel. For the comparison of right and leg reach distances, a paired sample t-test was calculated in Microsoft Excel for each normalized foot reach with the exception of the rotational reaches, which were not normalized.

A stepwise regression analysis was used to investigate the relative contribution of joint kinematics to SEBT normalized reach distance. Prior to the stepwise regression analysis, the Mahalanobis distance was used as a measurement to detect unusual combinations of all variables, thus considered outliers. Mahalanobis distance is calculated for each independent variable, using SPSS. The mahahanobis distance value is then compared with the chi-square distribution with the same degrees of freedom. This calculates the p-value of the right tail of the distribution. A mahalanobis distance with a p-value of lower than .001 is considered an outlier. With possible outliers removed, correlations are then calculated for all variables (joint movements) to the normalized reach distance. Variables with a non-significant correlation is discarded. The variables with a significant correlation is then investigated for multicollinearity, variables with a variance influence factor (VIF) of 10 is considered multicollinear and subsequently merged and averaged (Allison, 1999). Finally, the Stepwise multiple regression analysis was used to determine if or what joint movements that determines normalized reach distance. The normalized reach distance served as the dependent value, while joint movement (ankle and knee joint of stance foot, bilateral hip joints and spine) served as the predictor values. The stepwise regression added all significant correlated predictor values simultaneously into an initial model (Kang, Kim, Weon, Oh,

& An, 2015). However, if the number of correlated values was more than four, only the four highest correlated values was added to the stepwise regression analysis. For each regression step, a predictor variable was removed if it did not significantly contribute to the predictive value of the model.

3. Results

All tests had 20 subjects with the exception of the right stance left rotation and right rotation which had 19 and 18 subjects respectively due to recording failure.

The mean ± standard deviation for all reach directions of the right single leg stance is presented in figure 2.1 below.

3.1 Right and left foot stance

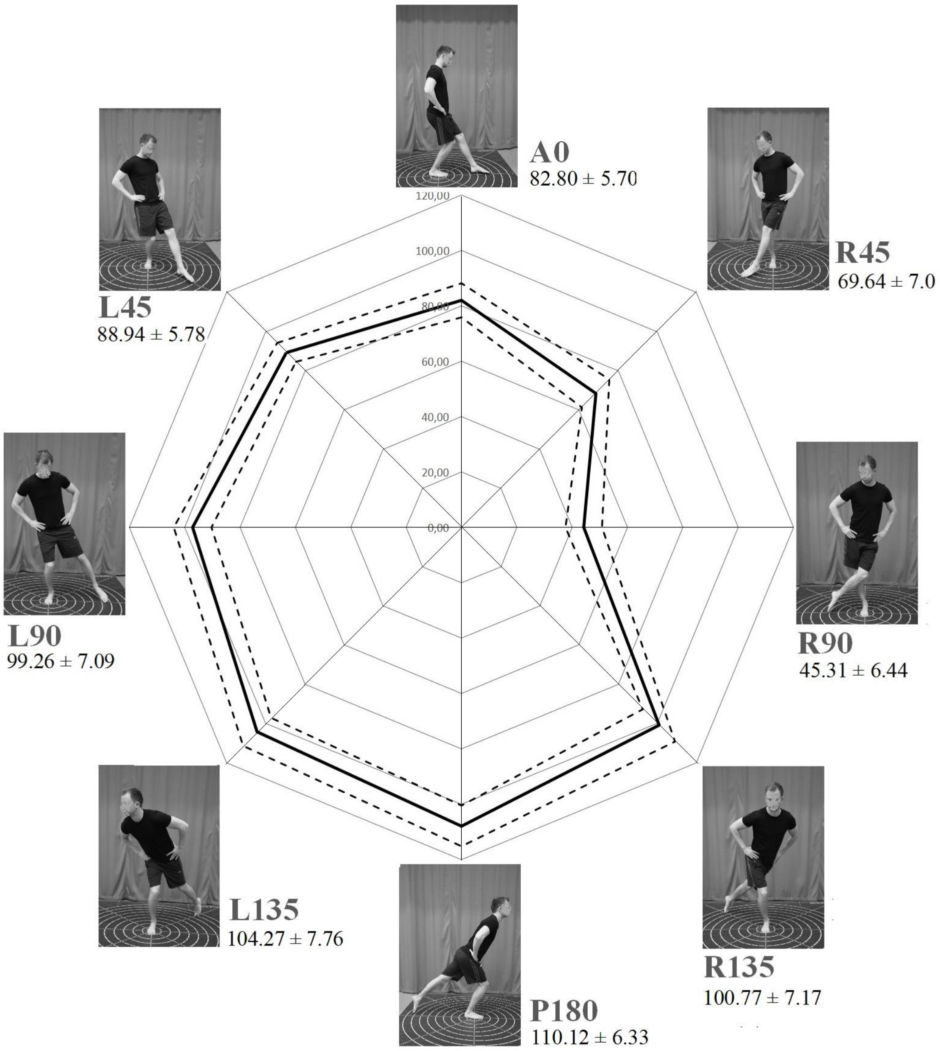

Figure 3.1.1 Horizontal reach scores when standing on the right leg with average normalized reach distance (black line) and standard deviation (dotted line).

Normalized reach distances are also presented in Table 3.3.2.

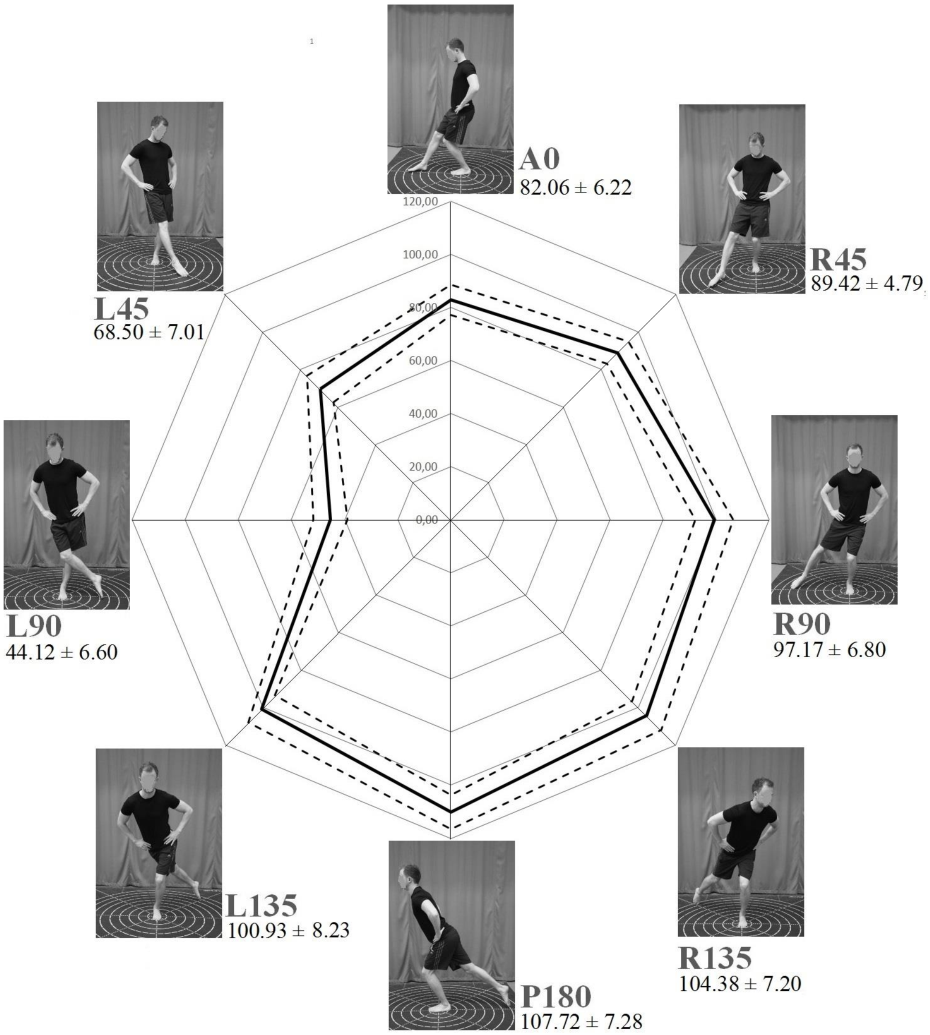

Figure 3.1.2 Horizontal reach scores when standing on the left leg with average reach distance in normalized percentage and black line. Dotted lines identify standard deviations.

Normalized reach distances are also presented in Table 3.3.2.

3.2 Rotations

The mean ± standard deviation for left and right single leg stance is presented in Figure 3.2.2 and Figure 3.2.1 below.

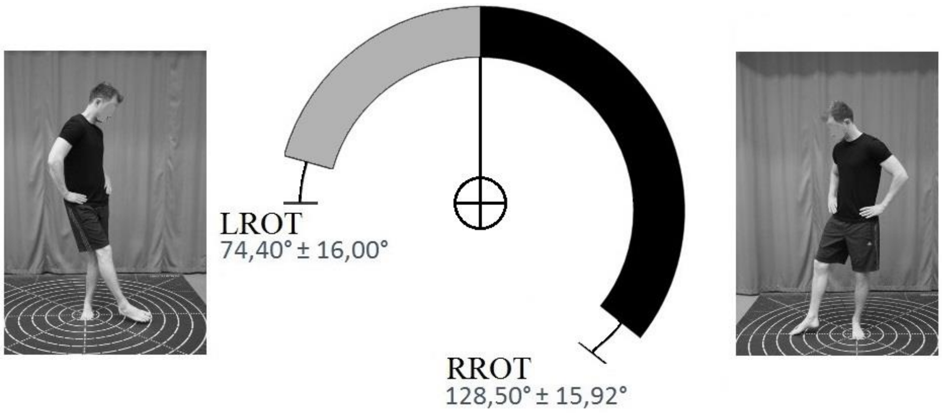

Figure 3.2.1 Left foot stance with right foot rotational reaches with standard deviations

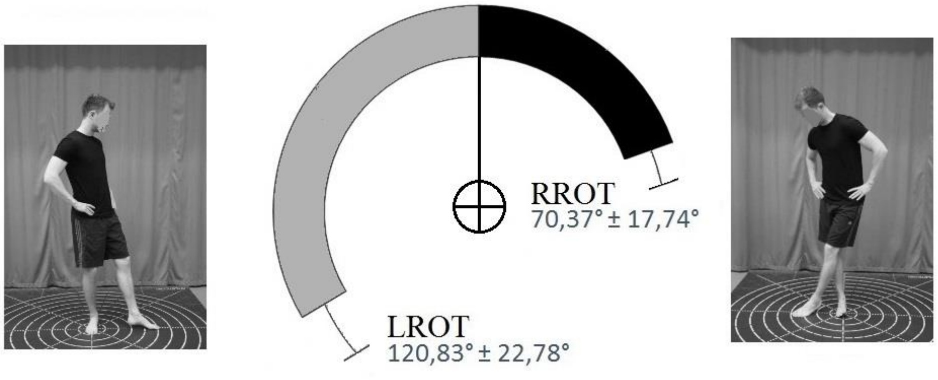

Figure 3.2.2 Right foot stance with left foot rotational reaches with standard deviations

Right and left lateral rotations at 128.50° ± 15.92° and 120.83° ± 22.78°, respectively. Left and right medial rotations at 74.40° ± 16.00° and 70.73° ± 17.74°, respectively.

3.2.1 Combined planes

R45 reach, test 1, is mainly predicted by stance foot dorsiflexion (32.88° ± 5.13°), accounting for 43.8% of the variance (F = 15.815, p<0.001). Similarly, the mirrored version test five, 46.4% of the variance of the L45 reach distance is also predicted by stance foot dorsiflexion (32.07° ± 5.29°) (F = 17.467, p<0.001).

The L135 reach, test 2, 86.7% of the reach distance is predicted by hip flexion (88.06° ± 10.70°) in the stance leg, less trunk flexion (12.93° ± 12.67°) and stance hip external rotation (18.45° ± 6.91) (F = 42.317, p<0.001). The mirrored reach, test 6, 21.0% is predicted by a decrease in stance hip adduction (11.93° ± 5.02) (F = 6.061, p<0.05).

Test 3, 28.6% of the L45 reach distance is predicted by left stance foot dorsiflexion (18.63° ± 8.25°) (F = 8.627, p<0.05). The right foot stance R45 reach has 35.1% of its reach distance predicted by internal rotation of the stance knee (9.10° ± 3.02°) and stance foot dorsiflexion (18.14° ± 7.14°) (F = 6.142, p<0.05).

For the R135 reach distance, test 4, 63.1% of the variance is predicted by stance leg hip flexion (84.79° ± 10.40°) and less trunk flexion (17.66° ± 14.45° flexion) (F = 17.216, p<0.001). Its mirrored version, test 8, is predicted by 47.6% stance knee flexion (69.85° ± 15.20°) (F = 17.216, p<0.001).

3.2.2 Pure Planes

The left foot stance anterior reach (test 9), has 52.7% of its reach distance predicted by stance foot dorsiflexion (31.34° ± 4.13°) and a reduction of stance foot eversion (4.67° ± 3.52°) (F = 11.566, p=0,001). For the right foot anterior reach (test 15), stance foot dorsiflexion (30.56° ± 5.21°) predicts 73.5% of its reach distance (F = 53.565, p<0.001).

Test 10, the P180 reach, 54.3% of the reach distance is predicted by trunk flexion (18.96° ± 12.67°) (F = 23.550, p<0.001). For test 16 (P180), 85.5% of the variance of the reach distance is predicted by a reduction of stance knee flexion (74.52° ± 12.42°), left hip abduction (6.46° ± 5.58°) and a reduction stance knee adduction (8.60° ± 6.71°) (F = 37.548, p<0.001).

Test 11, the left stance leg L90 reach distance is predicted by 63.3% with a reduction of stance leg knee flexion (78.03° ± 10.03°) (F = 33.793, p<0.001). For Test 17, the mirrored version of test 11, 72.1% the reach distance is predicted by a reduction of stance leg knee flexion (76.27°° ± 14.61°) reaching limb hip abduction (26.90° ± 6.77°) (F = 25.587, p<0.001).

The left foot stance R90 reach, test 12, had no significant predictors, however, its mirrored version, test 18, has a 29.9% prediction of its reach distance by reduced stance foot dorsiflexion (2.21° ± 3.24 plantarflexion) (F = 8.851, p<0.05).

3.2.3 Rotations

Stance hip abduction (8.09° ± 7.72°) explains 47.3% of the reach distance in test 13 left stance leg left rotation (F = 18.071, p<0.001). For the right stance right rotation (test 19), 68.0% of the reach distance is explained by a reduction of stance knee internal rotation (17.26° ± 6.05°) and reaching hip abduction (12.29° ± 8.43°) (F = 19.089, p<0.001).

For tests 14 left foot stance, right rotation, 45.9% of the reach distance is explained by a reduction in the stance foot plantarflexion (0.04° ± 4.94°) (F = 9.070, P <0.05). For the right foot stance, left rotation, 37.4% of the reach distance is explained by stance foot adduction (9.91° ± 4.67°) (F = 11.753, p<0.05).

3.3 Descriptive statistics

Table 3.3.1 Descriptive statistics of joint excursion

REACH	STANCE FOOT	TEST#	PLANE OF MOTION	FOOT	KNEE	HIP	REACHING HIP	TRUNK
R45	Left	1	Sagittal	**DF: 32,88 ± 5,13****^{X}	FL: 64,30 ± 14,97	FL: 18,75 ± 17,56	FL: 28,04 ± 11,82	FL: 7,2 ± 13,25
			Frontal	EV: 2,47 ± 4,43	ADD: 5,76 ± 5,76	ADD: 10,11 ± 5,63	ABD: 21,06 ± 5,89	LFL: 11,54 ± 6,76
			Transverse	ABD: 10,08 ± 2,31	IR: 0,02 ± 5,85	IR: 10,91 ± 7,39	ER: 11,40 ± 7,10	LROT: 2,49 ± 4,27
L45	Right	5	Sagittal	**DF: 32,07 ± 5,29****	FL: 63,63 ± 17,96	FL: 18,37 ± 22,42	FL: 29,96 ± 14,25	FL: 10,55 ± 15,15
			Frontal	EV: 2,5 ± 6,31	ADD: 0,62 ± 5,75	ADD: 10,77 ± 7,31	ABD: 20,24 ± 6,46	RFL: 11,73 ± 6,42
			Transverse	**ABD: 11,47 ± 2,27** ^{X}	ER: 3,11 ± 6,13	IR: 7,66 ± 9,73	ER: 12,56 ± 5,60	RROT: 3,03 ± 5,23
L135	Left	2	Sagittal	DF: 27,13 ± 5,00	FL: 64,07 ± 12,29	**FL: 88,06 ± 10,70****	FL: 5,40 ± 6,78	**FL: 12,93 ± 12,67****
			Frontal	EV: 8,10 ± 3,56	ADD: 3,79 ± 5,45	ADD: 12,36 ± 4,47	ADD: 5,95 ± 4,89	LFL: 15,51 ± 7,13
			Transverse	ABD: 8,59 ± 2,69	ER: 6,93 ± 5,27	**ER: 18,45 ± 6,91****	ER: 6,10 ± 6,26	RROT: 1,93 ± 5,18
R135	Right	6	Sagittal	DF: 23,78 ± 5,72	FL: 52,36 ± 12,63	FL: 69,85 ± 12,88	FL: 6,40 ± 7,43	FL: 8,80 ± 10,38
			Frontal	EV: 6,51 ± 3,33	ADD: 12,04 ± 6,93	**ADD: 11,93 ± 5,02***	ADD: 5,17 ± 4,12	RFL: 16,95 ± 8,16
			Transverse	ABD: 7,49 ± 2,53	ER: 8,47 ± 4,36	ER: 15,22 ± 8,15	ER: 4,93 ± 4,81	LROT: 0,92 ± 2,75
L45	Left	3	Sagittal	**DF: 18,63 ± 8,25***	FL: 39,15 ± 19,20	FL: 14,77 ± 14,31	FL: 42,01 ± 10,05	EX: 4,41 ± 10,24
			Frontal	EV: 5,52 ± 4,12	ADD: 3,79 ± 5,45	ADD: 18,06 ± 4,85	ADD: 5,47 ± 4,33	LFL: 0,89 ± 8,07
			Transverse	ADD: 4,68 ± 3,74	IR: 10,39 ± 3,76	IR: 12,78 ± 5,86	IR: 6,73 ± 8,22	LROT: 0,46 ± 3,52
R45	Right	7	Sagittal	**DF: 18,14 ± 7,14***	FL: 38,63 ± 16,93	FL: 13,97 ± 14,02	FL: 40,32 ± 10,50	EX: 3,69 ± 11,30
			Frontal	EV: 3,65 ± 3,91	ADD: 0,38 ± 6,44	ADD: 18,58 ± 4,66	ADD: 6,59 ± 5,00	RFL: 6,99 ± 8,45
			Transverse	ADD: 5,28 ± 4,51	**IR: 9,10 ± 3,02***	IR: 12,15 ± 4,45	IR: 5,04 ± 10,15	LROT: 0,42 ± 4,86
R135	Left	4	Sagittal	DF: 25,55 ± 5,84	FL: 71,93 ± 13,62	**FL: 84,79 ± 10,40****	FL: 5,35 ± 6,02	**FL: 17,66 ± 14,45****
			Frontal	EV: 3,93 ± 3,22	ADD: 6,14 ± 7,06	ADD: 9,37 ± 4,92	ABD: 19,76 ± 6,11	LFL: 13,37 ± 8,78
			Transverse	ABD: 4,64 ± 3,31	IR: 4,79 ± 4,40	IR: 9,35 ± 5,03	ER: 6,90 ± 7,85	LROT: 3,67 ± 4,52
L135	Right	8	Sagittal	DF: 25,35 ± 7,16	**FL: 69,85 ± 15,20****	FL: 82,60 ± 10,91	FL: 5,96 ± 7,64	FL: 16,06 ± 13,56
			Frontal	EV: 2,39 ± 4,37	ADD: 0,36 ± 6,28	ADD: 10,04 ± 8,41	ABD: 20,00 ± 7,39	RFL: 14,57 ± 6,95
			Transverse	ABD: 4,72 ± 5,39	IR: 3,68 ± 7,17	IR: 10,87 ± 7,04	ER: 7,19 ± 7,60	RROT: 5,24 ± 2,81
A0	Left	9	Sagittal	**DF: 31,34 ± 4,13****	FL: 66,68 ± 11,12	FL: 26,79 ± 15,86	FL: 44,94 ± 10,95	FL: 3,08 ± 17,13
			Frontal	**EV: 4,67 ± 3,52****	ADD: 6,41 ± 6,30	ADD: 16,96 ± 4,96	ABD: 4,72 ± 5,41	LFL: 6,12 ± 6,45
			Transverse	ABD: 6,87 ± 1,50	IR: 4,46 ± 5,29	IR: 12,02 ± 4,64	IR: 1,96 ± 7,21	LROT: 0,32 ± 2,95
A0	Right	15	Sagittal	**DF: 30,56 ± 5,21****	FL: 63,10 ± 11,26	FL: 22,06 ± 16,09	FL: 41,55 ± 11,68	FL: 3,81 ± 16,37
			Frontal	EV: 3,85 ± 2,92	ADD: 1,20 ± 5,56	ADD: 16,16 ± 5,26	ABD: 4,78 ± 6,13	RFL: 10,06 ± 6,61
			Transverse	ABD: 7,92 ± 2,31	IR: 1,94 ± 3,32	IR: 11,10 ± 6,07	ER: 1,25 ± 5,14	RROT: 1,59 ± 3,24
P180	Left	10	Sagittal	DF: 27,07 ± 5,11	FL: 75,95 ± 8,93	**FL: 95,35 ± 6,79** ^{X}	EX: 2,44 ± 6,93	**FL: 18,96 ± 12,67****
			Frontal	EV: 4,75 ± 3,33	**ADD: 13,05 ± 6,08**^{X}	ADD: 12,56 ± 4,31	ABD: 6,46 ± 5,58	LFL: 14,31 ± 4,90
			Transverse	ABD: 7,15 ± 2,10	IR: 0,01 ± 5,48	ER: 5,61 ± 6,37	ER: 10,36 ± 6,04	RROT: 2,21 ± 3,39
P180	Right	16	Sagittal	DF: 27,80 ± 5,25	**FL: 74,52 ± 12,42****	FL: 92,46 ± 10,42	EX: 2,44 ± 6,93	FL: 17,26 ± 14,79
			Frontal	EV: 5,70 ± 1,57	**ADD: 8,60 ± 6,71****	ADD: 15,02 ± 3,88	**ABD: 6,46 ± 5,58****	RFL: 15,59 ± 4,11
			Transverse	ABD: 8,99 ± 2,16	ER: 2,49 ± 7,45	ER: 2,90 ± 7,45	ER: 10,36 ± 6,04	RROT: 1,18 ± 2,80
R90	Left	11	Sagittal	DF: 30,72 ± 4,56	**FL: 78,03 ± 10,03**** ^{X}	FL: 66,12 ± 15,19	FL: 21,20 ± 10,06	FL: 10,71 ± 15,18
			Frontal	EV: 1,66 ± 4,52	ADD: 1,22 ± 5,85	ADD: 0,05 ± 6,72	ABD: 26,82 ± 6,28	LFL: 9,02 ± 9,16
			Transverse	ABD: 8,57 ± 2,61	ER: 5,04 ± 7,55	IR: 18,21 ± 4,83	ER: 8,15 ± 9,11	LROT: 2,52 ± 4,51
L90	Right	17	Sagittal	DF: 29,46 ± 6,18	**FL: 76,27 ± 14,61****	FL: 64,62 ± 12,43	FL: 22,43 ± 10,66	FL: 11,03 ± 10,70
			Frontal	EV: 1,21 ± 3,83	**ABD: 3,92 ± 6,15** ^{X}	ADD: 1,82 ± 7,69	**ABD: 26,90 ± 6,77****	RFL: 11,47 ± 7,37
			Transverse	ABD: 9,23 ± 3,38	IR: 1,25 ± 7,60	IR: 18,78 ± 5,11	ER: 6,33 ± 7,44	RROT: 4,58 ± 3,85
L90	Left	12	Sagittal	PF: 2,57 ± 3,35	EX: 8,65 ± 4,42	FL: 11,46 ± 7,63	FL: 36,52 ± 6,98	EX: 5,32 ± 9,41
			Frontal	EV: 12,06 ± 3,97	ADD: 1,97 ± 1,38	ADD: 22,95 ± 6,61	ADD: 5,40 ± 3,68	LFL: 2,67 ± 9,13
			Transverse	ADD: 0,67 ± 3,04	ER: 5,03 ± 5,51	IR: 1,81 ± 6,34	ER: 8,40 ± 6,74	RROT: 3,48 ± 3,27
R90	Right	18	Sagittal	**PF: 2,21 ± 3,24***	**EX: 9,40 ± 3,64**^{X}	FL: 14,01 ± 11,18	FL: 39,54 ± 7,54	EX: 5,22 ± 7,36
			Frontal	**EV: 12,15 ± 3,83**^{X}	ADD: 2,55 ± 1,23	**ADD: 23,55 ± 8,53** ^{X}	ADD: 4,31 ± 3,93	RFL: 4,72 ± 7,69
			Transverse	ABD: 0,64 ± 4,27	ER: 6,98 ± 5,02	IR: 2,34 ± 5,69	ER: 7,93 ± 6,09	LROT: 0,61 ± 5,76
RROT	Left	13	Sagittal	DF: 15,15 ± 8,05	FL: 25,25 ± 15,82	FL: 14,18 ± 7,46	FL: 13,04 ± 7,22	FL: 1,79 ± 8,16
			Frontal	EV: 3,81 ± 4,70	ADD: 6,73 ± 4,17	**ABD: 8,09 ± 7,72*** ^{X}	ABD: 13,24 ± 6,78	LFL: 1,72 ± 5,39
			Transverse	ABD: 8,81 ± 3,06	ER: 15,81 ± 4,99	ER: 27,07 ± 7,54	ER: 29,92 ± 6,53	RROT: 3,10 ± 9,83
LROT	Right	19	Sagittal	DF: 14,80 ± 5,77	FL: 21,33 ± 12,71	FL: 11,11 ± 9,22	FL: 17,70 ± 8,82	FL: 3,39 ± 6,82
			Frontal	EV: 4,98 ± 4,28	ADD: 5,79 ± 3,72	ABD: 3,51 ± 7,65	**ABD: 12,29 ± 8,43****	RFL: 1,66 ± 7,33
			Transverse	ABD: 9,37 ± 2,67	**ER: 17,26 ± 6,05**** ^{X}	**ER: 27,09 ± 6,75** ^{X}	ER: 24,65 ± 9,62	LROT: 3,10 ± 9,48
LROT	Left	14	Sagittal	**PF: 0,04 ± 4,94**	FL: 7,38 ± 11,41	FL: 10,11 ± 8,48	FL: 33,14 ± 7,70	EX: 3,84 ± 6,45
			Frontal	EV: 0,01 ± 5,98	ABD: 1,87 ± 2,13	ADD: 13,31 ± 3,81	ADD: 10,96 ± 4,82	LFL: 6,54 ± 6,97
			Transverse	**ADD: 11,45 ± 4,73**^{X}	**IR: 14,01 ± 4,72***^{X}	**IR: 20,21 ± 5,08** ^{X}	IR: 13,90 ± 6,04	LROT: 7,02 ± 6,91
RROT	Right	20	Sagittal	**PF: 0,07 ± 6,14***	FL: 7,07 ± 11,16	FL: 8,40 ± 8,80	FL: 34,61 ± 7,17	EX: 3,84 ± 7,97
			Frontal	EV: 2,55 ± 5,22	ABD: 3,33 ± 2,58	ADD: 12,23 ± 7,69	ADD: 10,79 ± 5,22	RFL: 4,42 ± 6,86
			Transverse	ADD: 9,91 ± 4,67	IR: 3,32 ± 5,05	IR: 18,49 ± 5,72	IR: 16,12 ± 5,60	RROT: 8,90 ± 6,13

*Statistically Significant Joint Excursion, $p \leq 0.05$, **Statistically Significant Joint Excursion, $p \leq 0.001$, ^{X}Greatest Joint Excursion of the Stance Leg.

Abbreviations: DF = Dorsiflexion; PF = Plantarflexion; E = Eversion; ABD = Abduction; ADD = Adduction; FL = Flexion; EX = Extension; ER = External rotation; IR = Internal rotation; LFL = Left lateral flexion; RFL = Right lateral flexion; LROT = Left rotation; RROT = Right rotation.

Table 3.3.2 Summary of paired t-test for all reaches.

PAIR	REACH	L. STANCE REACH DISTANCE (%)	R. STANCE REACH DISTANCE (%)	MEAN DIFFERENCE	STD. DEVIATION	STD. ERROR MEAN	CORRELATION	T	DF	SIG. (2-TAILED)
1 & 5	R45/L45	88,94 ± 5,78	89,42 ± 4,79	-0,48	3,15	0,70	0,839	-0,686	19	0,501
2 & 6	L135/R135	100,77 ± 7,17	100,93 ± 8,23	-0,16	5,69	1,27	0,736	-0,127	19	0,901
3 & 7	L45/R45	69,64 ± 7,09	68,50 ± 7,01	1,14	6,61	1,48	0,561	0,77	19	0,451
4 & 8	R135/L135	104,27 ± 7,76	104,01 ± 7,21	0,26	5,52	1,23	0,731	0,211	19	0,835
9 & 15	A0	82,49 ± 5,72	82,06 ± 5,72	0,43	3,61	0,81	0,820	0,532	19	0,601
10 & 16	P180	110,12 ± 6,33	107,72 ± 7,28	2,40	4,44	0,99	0,796	2,418	19	**0,026***
11 & 17	R90/L90	99,26 ± 7,09	97,17 ± 6,80	2,08	4,31	0,96	0,808	2,162	19	**0,044***
12 & 18	L90/R90	45,31 ± 6,44	44,12 ± 6,60	1,19	4,09	0,91	0,803	1,3	19	0,209
13 & 19	RROT/LROT	127,22° ± 15,94°	120,83° ± 22,77°	6,38	9,11	2,14	0,950	2,974	17	**0,009***
14 & 20	LROT/RROT	73,31° ± 15,66°	70,36° ± 17,74°	2,95	15,65	3,59	0,567	0,821	18	0,422

**Statistically significance difference, $p<0.05$*

Table 3.3.2 shows the paired t-test of normalized mean reach distances of the SEBT. The added rotations, test 13 & 19 and test 14 & 20, are not normalized to leg length. Test 10 & 16, test 11 & 17 and test 13 & 19 is the only tests that are significantly different, making the rest of the left and right mirrored tests reach distances statistically indifferent.

3.4 Stepwise regression analysis

Table 3.4.1 shows the results from the stepwise multiple regression analysis.

Table 3.4.1 Regression Equations

Reach	*Stance foot*	*Test#*	*n*	*Regression Equation*	*Statistical significance*	*R^2*	*Adjusted R^2*
R45	L	1	20	PR = 0,777 L foot DF + 63,568	F = 15,815, p<0,001	0,468	0,438
L45	R	5	20	PR = 0,636 R foot DF + 69,012	F = 17.467, p<0,001	0,492	0,464
L135	L	2	20	PR = 0,316 L Hip Flex – 0,286 Trunk Flex. + 0,341 L hip ext. rot. + 62,928	F = 42,317, p<0,001	0,888	0,867
R135	R	6	20	PR = -0,823 R Hip Add + 110,749	F = 6,061, p<0,05	0,252	0,210
L45	L	3	20	PR = 0,489 L foot DF + 60,531	F = 8,627, p<0,05	0,324	0,286
R45	R	7	20	PR = 0,970 R knee IR + 0,409 R foot DF 52,251	F = 6,142, p<0,05	0,419	0,351
R135	L	4	20	PR = 0,430 L hip flex – 0,194 trunk flex. +64,369	F = 17,216, p<0,001	0,669	0,631
L135	R	8	20	PR = 0,341 R knee flex + 80,355	F = 18,292, p<0,001	0,504	0,476
A0	L	9	20	PR = 0,836 L foot DF – 0,563 L Foot EV + 58,922	F = 11,566, p=0,001	0,576	0,527
A0	R	15	20	PR = 1,033 R foot DF + 50,491	F = 53,565, p<0,001	0,748	0,735
P180	L	10	20	PR = -0,376 Trunk flex + 102,989	F = 23,550, p<0,001	0,567	0,543
P180	R	16	20	PR = -0,326 R knee flex + 0,585 L hip Abd - 0,316 R knee add + 76,003	F = 37,548, p<0,001	0,876	0,852
R90	L	11	20	PR = -0,571 L knee flex + 54,696	F = 33,793, p<0,001	0,652	0,633
L90	R	17	20	PR = -0,261 R knee flex + 0,421 L hip Abd + 65,940	F = 25,587, p<0,001	0,751	0,721
L90	L	12	20	*No Correlations*			
R90	R	18	20	PR = -1,171 R foot DF + 41,531	F = 8,851, p<0,05	0,330	0,292
RROT	L	13	20	PR = 1,825 L hip Abd + 125,672	F = 18,071, p<0,001	0,501	0,473
LROT	R	19	18	PR = -2,607 R knee ER + 1,605 L hip Abd + 67,120	F = 19,089, p<0,001	0,718	0,680
LROT	L	14	20	PR = -2,065 L knee IR – 1,643 L foot DF + 52,248	F = 9,070, P <0,05	0,516	0,459
RROT	R	20	19	PR = 2,512 R foot DF + 51,598	F = 11,753, p<0,05	0,409	0,374

Abbreviations: PR = Predicted Reach; L = left; R = Right; Abd = Abduction; Add = Adduction; DF = Dorsiflexion; Flex = Flexion; Ext = Extension; EV = Eversion; IN = Inversion, LROT = Left rotation; RROT = Right rotation

Nineteen regression equations is presented in Table 3.4.1., with the highest adjusted R-squared at 0.867 for the left foot standing L135 reach. No significant regression equations were found for the left foot standing L90 reach (test 12).

3.5 Correlation table

Table 3.5.1 Correlation between normalized reach distance and joint excursion for the left foot standing tests.

Kine-matics / *Test #*	*L FOOT DF (+) /PF*	*L FOOT EV (+)/INV*	*L FOOT ABD (+)/ADD*	*L KNEE Flex/Ex (+)*	*L KNEE ABD (+)/ADD*	*L KNEE IR/ER (+)*	*L HIP Flex (+)/Ex*	*L HIP ABD (+)/Add*	*L HIP IR/ER (+)*	*R HIP Flex (+)/Ex*	*R HIP ABD/Add (+)*	*R HIP IR (+)/ER*	*TRUNK FLEX/EX (+)*	*TRUNK R LATFLEX (+)/L LATFLEX*	*TRUNK R ROT/L ROT (+)*
Test 1	**,684****	-,418	**,635****	**-,527***	-,135	,279	,109	-,225	,125	,178	-,245	-,140	-,149	-,079	,046
Test 2	**,487***	-,180	,340	**-,704****	-,118	-,065	**,742****	,279	**,505***	-,247	-,482*	**-,662****	**-,738****	,282	**-,456***
Test 3	**,569****	-,231	-,286	**-,505***	-,342	**-,447***	,252	-,204	,044	,047	-,335	-,327	-,113	-,361	-,271
Test 4	**,501***	-,268	,225	**-,740****	-,182	-,235	**,755****	-,366	-,041	-,224	-,383	**-,506***	**-,647****	-,333	-,194
Test 9	**,680****	**-,478***	,272	-,083	-,091	,102	-,429	,251	,272	-,354	,012	-,332	,332	-,397	,061
Test 10	,341	,023	,169	**-,603****	-,044	-,196	,305	-,030	,328	-,422	-,265	-,121	**-,753****	,040	-,053
Test 11	**,526***	-,409	-,121	**-,808****	**-,463***	-,246	**,533***	-,348	**-,519***	-,018	-,418	-,415	-,411	-,019	-,274
Test 12	-,339	,085	-,272	,396	-,213	-,253	-,101	-,302	-,261	-,060	,022	-,165	-,012	,290	-,067
Test 13	,402	-,386	,259	**-,480***	**-,578****	**,611****	,411	**,708****	**,559***	,022	-,215	-,298	-,397	,095	,025
Test 14	**-,475***	-,410	**-,554***	,404	,175	**-,561***	-,246	-,043	-,112	-,108	**,461***	,115	-,031	-,061	,183

** Correlation is significant at the 0.05 level (2-tailed).*

*** Correlation is significant at the 0.01 level (2-tailed).*

Table 3.5.1 shows the Pearson Correlation value for between the normalized reach distance and the maximum joint excursion for the left foot standing SEBT number 1-4 and 9-14.

Table 3.5.2 Correlation between normalized reach distance and joint excursion for the right foot standing tests.

Kine-matics / *Test #*	*R FOOT DF (+) /PF*	*R FOOT EV/INV (+)*	*R FOOT ABD/ADD (+)*	*R KNEE Flex/Ex (+)*	*R KNEE ABD/ADD (+)*	*R KNEE IR (+)/ER*	*L HIP Flex (+)/Ex*	*L HIP ABD (+)/Add*	*L HIP IR/ER (+)*	*R HIP Flex (+)/Ex*	*R HIP ABD/Add (+)*	*R HIP IR (+)/ER*	*TRUNK FLEX/EX (+)*	*TRUNK R LAT FLEX (+)/L LAT FLEX*	*TRUNK R ROT/L ROT (+)*
Test 5	**,702****	,182	-,167	-,328	,124	,013	-,153	-,108	,243	-,196	-,088	-,344	-,050	,111	-,149
Test 6	-,027	,058	-,051	-,037	,027	-,201	-,132	,237	,128	,122	-**,502***	-,144	-,349	-**,468***	-,070
Test 7	**,502***	,101	,303	-,358	,192	**,504***	-,112	,363	,171	-,014	**,469***	-,196	,124	-,010	,273
Test 8	**,577****	-,062	-,325	-**,710****	,161	-,034	-,044	,409	,368	**,643****	,153	-,139	-,467*	,433	,022
Test 15	**,865****	-,119	,018	-,466*	,150	,154	-,103	,210	,368	-,116	,175	-,248	,334	,244	,075
Test 16	**,456***	,161	-,013	-**,792****	**,546***	**,506***	-,413	**,703****	,281	**,535***	-,293	-,013	-,338	,065	-,322
Test 17	**,657****	,172	-,214	-**,793****	-,024	-,204	,098	**,730****	,433	**,625****	**,610****	,104	-,419	,003	,082
Test 18	-**,574****	-,308	,400	**,470***	,115	,032	,188	-,051	,257	,315	**,448***	-,303	-,376	-,378	,438
Test 19	,628**	-,035	-,236	-,457	,126	**-,691****	**-,638****	**,626****	,254	,361	-,146	-,446	-,455	-,276	,014
Test 20	-**,527***	,310	,639**	,306	-,021	**,504***	,036	-,284	-,243	-,103	,049	,305	-,080	,356	-,039

** Correlation is significant at the 0.05 level (2-tailed).*
*** Correlation is significant at the 0.01 level (2-tailed).*

Table 3.5.2 shows the Pearson Correlation value for between the normalized reach distance and the maximum joint excursion for the right foot standing SEBT number 5-8 and 15-20.

4. Discussion

The main findings in this study is that ankle dorsiflexion is highly correlated with normalized reach distance in all reach directions (not bilaterally) followed by knee flexion. Only one reach direction has identical regression equations for left and right tests, which indicates laterality in movement strategy, or that other qualities than specific joint movements determine reach distance. Furthermore, the SEBT elicit ankle dorsiflexion, and knee rotations within ROM reference values.

4.1 Ankle Movement

The largest ankle sagittal motion was elicited during left foot stance R45 reach with a dorsiflexion of 32.88° ± 5.13°, which is almost identical to the mirrored test in right foot stance, L45 reach, with a dorsiflexion of 32.07 ± 5.29 (Table 3.3.1). ROM reference values for dorsiflexion varies in the literature. Grimston and coworkers (1993) reported a dorsiflexion of 25.6° ± 1.2° within a similar group of subjects, which is within the range, 13-30°, found elsewhere in the literature (Grimston, Nigg, Hanley, & Engsberg, 1993; Levangie & Norkin, 2011; Schuenke, Schulte, & Schumacher, 2009; Soucie, et al., 2011). In the study by Soucie and coworkers (2011) passive ROM with traditional goniometry was used (Soucie, et al., 2011), while and Grimston and coworkers (1993) used a fixture developed for in vivo measurements to measure active ankle motion. The latter study underestimates dorsiflexion ROM, because the load from bodyweight in weight-bearing position is greater than the active force the antagonistic muscle group of the lower leg can produce. During the aforementioned reaches, the knee moves into flexion, which also contributes to dorsiflexion when in a closed kinetic chain (Baumbach, et al., 2014; Hoch, Staton, & McKeon, 2011). If the knee exceeds 20° of flexion, the tension from the biarticular gastrocnemius muscle is removed from the ankle, effectively limiting the dorsiflexion by the tension from the uniarticular soleus muscle (Baumbach, et al., 2014). The addition of ankle abduction and eversion (pronation) have also been shown to increase dorsiflexion (Tiberio, Bohannon, & Zito, 1989), and the right foot standing L45 reach elicited the highest ankle abduction motion of 11.47° ± 2.27° (Table 3.3.1). The stepwise multiple regression analysis for the L/R45 reach direction also indicate dorsiflexion as the main contributor to normalized reach distance (NRD). For the R45 reach, left ankle dorsiflexion explains 43.8% (p<.001) of the NRD while for the opposite leg, dorsiflexion explains 46.4% (p<.001) of the NRD

(Table 3.4.1). Therefore, the R45/L45 (anteromedial) reach is excellent in evaluating maximum ankle dorsiflexion, and a decreased performance may be indicative of soleus muscle tightness or other ankle pathology related to a decreased dorsiflexion (Olmsted, Carcia, Hertel, & Schultz, 2002), such as ankle hypomobility or posterior talar glide deficiency (Green, Refshauge, Crosbie, & Adams, 2001).

The stepwise regression analysis also revealed dorsiflexion as a major contributor for the right foot R45 and left foot L45 reach, as well as the A0 reach (both legs). For the left foot L45 reach, an ankle dorsiflexion of 18.63° ± 8.25° explains 28.6% of the reach variance ($p<.05$). The NRD is also lower, with anterolateral L/R45 NRD of approximately 89 ± 5% and the anteromedial L/R45 NRD of approximately 69 ± 7%. The mirrored version of the left foot L45, the right foot R45 has its main contributor as internal knee rotation and dorsiflexion explaining 35.1% of the variance of NRD. Knee flexion is also reduced in the anterolateral reach direction when compared to the anteromedial reach direction. In addition, the ankle goes into adduction and inversion, facilitating a closed packed position of the ankle joint complex, which reduces the capacity of the ankle joint complex in producing dorsiflexion by limiting mobility of the mid- and forefoot in the sagittal plane (Johanson, et al., 2014), reducing the reaching distance of the subject when performing the SEBT. Thus, the main predictor of the NRD in the anterolateral L/R45 reach may be dorsiflexion, with its restrictor appearing to be ankle adduction and inversion. The A0 reach also elicited a significant amount of dorsiflexion: for the left stance leg, 31.34° ± 4.13° degrees of dorsiflexion together with a reduction of ankle eversion explains 52.7% of the reach variance ($p=.001$). For the right foot, a dorsiflexion of 30.56° ± 5.21° alone explains 73.5% of the reach variance. Ankle abduction is slightly less than in the anteromedial direction, but knee flexion is about the same. The NRD in the A0 is also slightly less than the anteromedial direction, with an NRD of 82.49 ± 5.72 and 82.06 ± 5.72, for the left and right leg respectively. This is concurrent with others who found dorsiflexion as the main predictor in the anterior reach distance (Kang, Kim, Weon, Oh, & An, 2015). Furthermore, dorsiflexion is correlated with NRD of all SEBT reach directions (not bilaterally), except for the lateral rotations in our study, which is not designed to elicit dorsiflexion (Table 3.5.1 & Table 3.5.2). The highest correlation is found in the right foot standing A0 reach, with a Pearsons correlation coefficient of 0.865 ($p < .01$).

There are SEBT tests thought to elicit frontal plane movement of the ankle more than others. On average, no test found ankle inversion to be elicited by the SEBT, but the standard deviation crosses zero during multiple reach directions (Table 3.3.1). Even tough inversion in itself was not found to be elicited or significant in any reach direction the least amount of eversion was found to predict reach distance. In left foot standing A0 reach, both dorsiflexion and eversion, with a negative sign, (Table 3.4.1) was found to predict reach distance. The greatest ankle eversion of 12.15° ± 3.83° was elicited by the right foot standing R90 reach test which is below ROM reference value of ~40° (Macedo & Magee, 2009). Using a portable ankle arthrometer, Kovaleski and coworkers (1999) investigated ankle inversion-eversion ROM by applying external loads ranging from 2000N-mm to 4000N-mm: they found a total inversion-eversion ROM of 25.63° to 47.38° with the 2000N-mm and 4000N-mm load, respectively (Kovaleski, Gurchlek, Heitman, Hollis, & Pearsall IV, 1999). Doherty and coworkers (2015b) presented a slightly greater eversion than in our study, with a joint excursion of 16.53° ± 19.55° during performance of the SEBT in the posterolateral direction (Doherty, et al., 2015b), and in agreement with our study, they also presented a standard deviation, even though large, that crosses zero, indicating that some subjects ended up in an inverted position at maximum reach. Consequently, our study suggests that the SEBT does not challenge ankle frontal ROM.

In the transverse plane the greatest ankle abduction of 11.47° ± 2.27° was elicited by the right foot standing L45 reach (Table 3.3.1). This is less than the reference value of 13° – 30° abduction (combination of abduction and eversion) (Macedo & Magee, 2009; Schwartz, Kovaleski, Heitman, Gurchiek, & Gubler-Hanna, 2011). Our results are similar to the SEBT results from Doherty and coworkers (2015b) of 14.84° ± 10.33° (Doherty, et al., 2015b). The greatest ankle adduction of 11.45° ± 4.73° was elicited by the right foot standing right rotational reach. With a reference value of 20° – 62° (combination of adduction and inversion) (Macedo & Magee, 2009; Schwartz, Kovaleski, Heitman, Gurchiek, & Gubler-Hanna, 2011), our results suggest that the SEBT do not challenge ankle adduction. It is, however, correlated with rotational reach performance in left foot standing left rotation (r = .554, p=0.05, Table 3.5.1) but deemed an insignificant contributor by the stepwise regression analysis (Table 3.4.1).

4.2 Knee movement

The largest knee flexion ROM occurred in the left foot standing R90 reach direction, with a total of 78.03° ± 10.03° (Table 3.3.1). This is far less than ROM normative reference values of 136° – 148° (Soucie, et al., 2011; Macedo & Magee, 2009). According to the stepwise regression analysis, knee flexion explains 63.3% of the variance of the NRD in this direction. As explained earlier, in a closed kinetic chain, there has to be an interaction between knee flexion and ankle dorsiflexion. A dorsiflexion ROM of 30° was found in this direction, and together with ankle abduction these were the predictors. For the mirrored version, right foot standing L90 reach, knee flexion with reaching hip abduction explains 72.1% of the variance of the NRD in this direction. Robinson and coworkers (2008b) reported a knee flexion of 55.87° ± 22.33° in this (medial) direction. Additionally, in their study, a hip flexion of 46.30° ± 25.37° explained 86.4% if the variance of reach performance, and together with knee flexion, 88.2% of the variance was explained (Robinson & Gribble, 2008b). In our study, both knee flexion and hip flexion ROM was considerably higher than the study by Robinson and coworkers (2008b) in this direction. The difference of joint ROM could be a consequence of averaging three trials, while our study used the maximum reach of three trials. Lower scores for knee flexion than our study is also found in the study by de la Motte and coworkers (2015) who presented a maximum knee flexion of 61.07° ± 16.18° in the medial direction (uninjured group) (de la Motte, Arnold, & Ross, 2015). In our study the knee flexion angle elicited is between 38° and 78° (Table 3.3.1). This might indicate that other factors than joint movements are important such as strength. The peak torque produced by the quadriceps muscle is often seen in a knee flexion range of 45° – 60°, which is due to the muscle’s maximization of moment arm and length-tension relationship (Trezise, Collier, & Blazevich, 2016). Thus, the SEBT do not challenge sagittal knee ROM, but performance might be more associated with quadriceps strength. A reduced reach distance in this direction may be indicative of quadriceps weakness.

No test was expected to elicit knee extension since the SEBT is based on different single leg squats. One could think that the rotational test would lead to knee extension, however this was not found.

The largest excursion of knee adduction was elicited during left foot standing P180 reach (posterior reach) of 13.05° ± 6.08°. For knee abduction, a maximum of 3.91° ± 6.15° was elicited during the right foot standing L90 reach. Normative ROM in the frontal plane has been found to be 13° at 20° of knee flexion (Levangie & Norkin, 2011), which smaller than the maximum arc of 17° found in this study. Doherty and coworkers (2015b) also presented values within the presented movement arch, however they did not analyze the posterior direction. Furthermore, the importance of knee frontal plane movement can be discussed since the regression analysis only finds knee adduction as one of the predictors in one reach direction, the right foot standing P180 reach (Table 3.4.1).

The greatest transverse plane movements of the knee were found with the rotational reaches, which is not surprising. The greatest knee external rotation of 17.26° ± 6.05° was elicited by the right foot standing left rotational reach (Table 3.3.1). This is, according to the stepwise regression analysis, also predictive and explains 68% of the variance of the maximum rotation together with reaching hip abduction (Table 3.4.1). The knee external rotation found in this study is within the reference value of 6° – 19° (Almquist, et al., 2002). The greatest knee internal rotation of 14.01° ± 4.72° was elicited by the left foot standing left rotation (Table 3.3.1). This is greater than the reference value of 6° – 13° (Almquist, et al., 2002). Together with a reduction of ankle dorsiflexion, knee internal rotation explains 45.9% of the variance of the maximum rotation in this direction ($p<.05$, Table 3.4.1). Kang and coworkers (2015) presented their greatest internal knee rotation of 26.64° ± 6.37° to not be significant to NRD in the posteromedial reach direction (Kang, Kim, Weon, Oh, & An, 2015) and Doherty and coworkers (2015b) reported a maximum internal knee rotation of 5.31° ± 14.72° during performance of the posterolateral direction (Doherty, et al., 2015b). Their particular high standard deviation suggests that knee internal rotation was not specific to reach distance and thus not predictive. Both methods and normative ROM reference values varies in the literature when measuring knee rotation. Almquist and coworkers (2002) evaluated knee rotation by using a *rottometer* which applies constant torque (3 and 9 Nm) while in 90° and 60° of knee flexion until the subjects reaches their limit of comfort. Simultaneously, specific radiographic stereometric analysis was used to test in vivo joint rotation. Their measured external rotation results from the radiographic analysis during the testing with the rottometer increased from 13° to 19° when using

3Nm and 9Nm at 90° of knee flexion, respectively. At 60° of flexion, their results were 6° and 15° at 3Nm and 9Nm (Almquist, et al., 2002). Applying external loads on subjects with damaging potential is not ethical, and is the reason why many studies use cadaver models to test human kinematics while applying external loads (Lam, Fong, Yung, & Chan, 2012). When using a motion capture system with reflective markers attached to the skin, the measurement error due to skin movement is a challenge, and even more so if the subjects has thick skin (Taylor, et al., 2005). As such, the SEBT with the rotational tests, may be a more ethical and functional method of evaluating knee rotation, however potentially harmful as excessive knee rotation is associated with many injuries.

4.3 Hip movement: stance leg

No stance leg hip extension was found during this study, which is not surprising considering that the SEBT is based upon single leg squats. The largest hip flexion was found in the left foot standing P180 reach direction, with a flexion of 95.35° ± 6.79° (Table 3.3.1). This is less than normative ROM values of approximately 130° (Soucie, et al., 2011), and more than values reported earlier for the SEBT (55.87° – 76.99°) (Robinson & Gribble, 2008b; Kang, Kim, Weon, Oh, & An, 2015). This particular reach also elicits one of the largest ROM of knee flexion and dorsiflexion, together with the greatest NRD in the SEBT: 110.12% ± 6.63% for the left stance foot. According to the stepwise regression analysis, the left foot standing L135 reach and the left foot standing R135 reach is the only reach directions with hip flexion as one of the main predictors of NRD with a reduction of trunk flexion (Table 3.4.1). Robinson & Gribble (2008b) reported hip flexion as a main predictor of reach distance in all the posterior reach directions as well as the medial. Together with knee flexion, it accounted for the majority of the explained variance in the anterior and lateral reaches. They also found the largest hip flexion during the posterior reach, but only 58.42° ± 26.75° (Robinson & Gribble, 2008b). Kang and coworkers (2015) found slightly less hip flexion excursion during the posteromedial and posterolateral directions, with a maximum hip flexion of 72.99° ± 10.31° and 76.99° ± 11.68°, respectively. Delahunt and coworkers (2013) reported a reduced NRD in ACL-R subjects compared to healthy subjects in the posteromedial and posterolateral directions with a concurrent reduction of hip flexion. Lowering the center of mass by flexion in the knee and hip increases the demand of force production by large muscles, such as the quadriceps and the gluteus maximus

(Bryanton, Carey, Kennedy, & Chiu, 2015). With ACL-D/R follows a disruption to the mechanoreceptors which alters the proprioception the quadriceps muscle, consequently disrupting the neuromuscular control of the knee (Roberts, Friden, Zatterstrom, Lindstrand, & Moritz, 1999). Thus, the posterior directions (L/R135, P180 & R/L135) elicits the greatest hip flexion as well as knee flexion (Table 3.3.1) in the stance leg, making these reach directions ideal when monitoring effects of rehabilitation interventions for people with ACL-D/R or other quadriceps/hip extensor dysfunctions. Also, posterior reaches are independent of visual feedback on reach performance possibly putting a greater demand on the somatosensory and vestibular system. Supporting this theory, Delahunt and coworkers (2013) found multiplanar deficiencies in hip and knee kinematics during performance of the YBT in ACL-R females compared to a control group. Their main findings were reduction of sagittal hip and knee motion, as well as a reduction of reach distance in all directions (Delahunt, et al., 2013), indicating other factors that isolated joint movements in themselves.

The greatest stance hip adduction of 23.55° ± 8.53° was elicited by the right foot standing R90 reach (Table 3.3.1). This is within the reference value of 15° – 31° (Macedo & Magee, 2009; Roaas & Andersson, 1982). No specific joint movement correlated with NRD during performance of this reach direction, probably because of the reach leg moving directly anterior to the stance leg thus inhibiting flexion during a single leg squat (Table 3.5.1). Thus, even though this reach direction elicited the greatest stance hip adduction, it is not predictive of NRD. Robinson and Gribble (2008b) found a maximum hip adduction in the posterolateral reach direction, with a joint movement of 13.94° ± 41.00°. Their standard deviation of 41.00° makes the result of hip adduction debatable because some of the subjects may have used hip abduction or an adduction far beyond any normative ROM reference values. In a closed kinetic chain, hip adduction indicates contralateral movement of the trunk, consequently increasing the load on the hip abductors (Takacs & Hunt, 2012), and hip abductor deficiency has been associated as a predisposing factor of ACL injuries (Anderson, Browning, Urband, Kluczynski, & Bisson, 2016; Geiser, O'Connor, & Earl, 2010). Using a hip abduction movement solution in a closed kinetic chain, the trunk moves ipsilateral (Table 3.3.1), effectively reducing the loads to the hip abductors by reducing their moment arm (Levangie & Norkin, 2011). Thus, such a movement solution may be compensatory for hip abductor weakness. Although frontal plane hip movement is not significant for NRD in this reach direction, the direction may be ideal for clinicians to evaluate hip movement quality in terms of risk of ACL injury. In our study, hip adduction is also present during the posterolateral reach, however, our measured total hip adduction was 9.37° ± 4.92° and 10.04° ± 8.41° for the left and right stance leg, respectively (Table 3.3.1). As such, few of our subjects used the hip abduction solution in the reach direction, indicating no kinematic compensatory strategies of hip abduction weakness.

The greatest stance hip abduction of 8.09° ± 7.72° was elicited by the left foot standing right rotational reach (Table 3.3.1). This does not challenge the normal ROM reference value of hip abduction of 42° – 60° (Greene & Heckman, 1994; Macedo & Magee, 2009), so the SEBT does not challenge hip abduction. The hip abduction in our study is both less (Robinson & Gribble, 2008b) and approximately same (Kang, Kim, Weon, Oh, & An, 2015) than what has been reported previously for the SEBT

The greatest stance hip external rotation of 27.09° ± 6.75° was elicited by the right foot standing left rotational reach with equal results for the mirrored version (Table 3.3.1). This does not challenge the ROM normative reference value of 38° – 45° (Greene & Heckman, 1994; Macedo & Magee, 2009). The hip external rotation movement found in this study is both greater (Doherty, et al., 2015b; Robinson & Gribble, 2008b), and less (de la Motte, Arnold, & Ross, 2015) than what has been reported previously for the SEBT. The greatest hip internal rotation of 20.21° ± 5.08° was elicited by the left foot standing left rotation (Table 3.3.1). This is less than the reference value of 30° – 45° (Macedo & Magee, 2009; Greene & Heckman, 1994; Krause, Hollman, Krych, & Levy, 2015). Additionally, hip internal rotation is not considered significant to maximum rotation during this rotational reach (Table 3.4.1). Our findings are greater than what was established by Kang and coworkers (2015) of 8.01° ± 7.26° internal hip rotation in the anterior direction, but less than the findings of Delahunt and coworkers (2013) of 22° of internal hip rotation during the posterolateral reach (Kang, Kim, Weon, Oh, & An, 2015; Delahunt, et al., 2013). The transverse movements of the hip are not consistently greater in the new rotational reaches than other studies on the SEBT as we would have thought. For instance, when performing the left foot standing R135 reach direction, the rotational angle from the center of the grid is set at 135° relative to the anterior direction. This will limit the combined stance leg rotation to 45° for the ankle, knee and hip unless different rotational strategies of these joint during the movement are chosen. When performing the new rotational reaches, the hip is in a slightly flexed position (Table 3.3.1). Thus, rotational reaches become a combination of internal rotation and adduction or external rotation and abduction, depending on the direction of the rotation. This is emphasized in our results: the maximum hip abduction and hip external rotation was elicited by the left foot standing right rotation (lateral rotation) and internal rotation and adduction is seen in the medial rotations (Table 3.3.1). The movement pattern of the hip elicited by the lateral rotations is the same movement as the FABER Test (also called the Patrick's Sign): pain during this test, or during performance of the lateral rotations, could potentially be a standing femoroacetabular impingement or labral pathology such as acetabular labral tear (Tijssen, Cingel, Willemsen, & de Visser, 2012; Martin, Irrgang, & Sekiya, 2008). Additionally, the lateral rotators of the hip, the piriformis, gemellus, obturatorius and quadratus femoris muscles, has a significant effect on load transfer in the human hip (Weissgraeber, Wall, Khabbazeh, & Becker, 2012) and any deficits or alterations of neuromuscular control can alter the mechanical loading which consequently has a high impact on the onset and progression of osteoarthritis (Felson, et al., 2000). According to Levangie and Norkin (2011), there are no muscles of the hip with a primary function of internal hip rotation (Levangie & Norkin, 2011), however many contribute. When the hip flexes, moment arm for medial rotation for the gluteus medius muscle increases (Delp, Hess, Hungerford, & Jones, 1999; Levangie & Norkin, 2011). This makes hip flexion movement pattern ideal when trying to medially rotate as far as possible. As such, the new rotational reaches do not challenge normative hip ROM transverse plane motion, however more research is needed to determine if these reaches might in fact be more sensitive to musculoskeletal pathology strength differences. However, the rotational reaches elicit multiplanar joint movement of the lower extremity and might add an investigative value to the current SEBT.

4.4 Side by Side Comparisons

Three reach directions were significantly different from side to side; 1) P180, 2) left foot standing R90 and right foot standing L90 and 3) left foot standing right rotation and the right foot standing left rotation Table 3.3.2. Not only the reach performance is different, but also the predictive model for the P180 reach is different. The right stance leg P180 reach is explained by knee flexion, reaching hip abduction and stance leg knee adduction (Adjusted $R^2 = 0.852$), while the mirrored version is explained by trunk flexion (Adjusted $R^2 = 0.543$) (Table 3.4.1). The learning effect in this direction is documented (Hertel, Miller, & Denegar, 2000), and this could make the left stance leg P180 reach test the most valid. Furthermore, all participants in our study are right foot dominant. The major kinematic difference between these mirrored reaches is the 5° reduction of stance knee adduction from the right foot standing compared to the left foot standing (which is the greatest knee adduction found in our analysis).

Although the right foot standing L90 and left foot standing R90 reach directions are different in NRD, the stepwise regression equation appears to be similar to a certain degree: both are associated with a reduction of stance knee flexion, and the right foot standing reach is also associated with left hip abduction. Both equations explain approximately the same variance (63.3% and 72.1% for the left foot standing and right foot standing, respectively (Table 3.4.1)). However, the addition of the reaching hip abduction strengthens the right foot standing L90 reach equation. As with the P180 reach, this reach direction also has kinematic differences occurring mainly at the knee: the left stance foot induces adduction and external rotation, while the right stance foot induces abduction and internal rotation. However, the motions for the knee joint in the transversal plane has standard deviations which is greater than the average joint movement, making the conclusion of transverse knee joint motion difficult in this reach direction. De la Motte and coworkers (2015) also found large variations of knee movements in the medial reach in the transversal plane, but not in the frontal plane (de la Motte, Arnold, & Ross, 2015).

When instructing the subjects how to move during the SEBT, the subject does not receive any information on how the particular movement is performed, just the general information about the restrictions, i.e. heel contact at all times and hands on the hips etc. This enables the SEBT to evaluate, not only the reach distance, but how the individual chooses to solve the task (Ness, Taylor, Haberl, Reuteman, & Borgert, 2015). This is reflected by the all the regression equations in Table 3.4.1. Only one equation pair has the same solution, the left foot standing R45 reach and the right foot standing L45 reach, which is only explained by ankle dorsiflexion. All other movement equations have one or more different kinematic variable connected to the variance than its respective mirrored version. The most different regression equation pair is the left foot standing L135 reach and the right foot standing R135 reach (posterolateral reach). Explaining 86.7% of the variance, the primary joint movements contributing to the reach distance of the left foot standing L135 reach consists of standing hip flexion, a reduction of trunk flexion and standing hip external rotation ($p<0.001$) (Table 3.4.1). For the mirrored version, the right foot R135 reach, only a reduction of standing hip adduction is considered significant for NRD, explaining 21% of the variance ($p<0.05$) (Table 3.4.1). The NRD is practically identical 100.77 ± 7.17% and 100.93 ± 8.23% for the left and right stance leg respectively with a mean difference of -0.16 ± 5.69 (Table 3.3.2). This is similar to the results from a study by Fulham and coworkers (2014) and Doherty and coworkers (2015b), presenting a NRD of 99.71 ± 8.67% and 101.14 ± 8.39%, respectively (Fullam, Caulfield, Coughlan, & Delahunt, 2014; Doherty, et al., 2015b). Even though the reach distance is almost identical, the movement strategies are different for each leg in this direction. The correlation between stance hip flexion and NRD for the left foot standing is 0.742, which is significant at the $\alpha = 0.01$ level. For the mirrored version, the right foot standing, the same correlation is 0.132, which is very weak (Table 3.3.1). In a study by Robinson & Gribble (2008a) they reported a correlation between hip flexion and posterolateral NRD (F-ratio = 4.63, p=.001), supporting the movement equation of the non-dominant limb in this particular reach direction (Robinson & Gribble, 2008a). Additionally, the same authors presented a regression model consisting of stance hip flexion, abduction, rotation and stance knee flexion as the kinematic predictors of the posterolateral reach, further supporting our left foot stance equation as the most valid compared to our right foot stance equation (Robinson & Gribble, 2008b). The two aforementioned studies by Robinson and Gribble (2008a and 2008b) uses the same participants and arguably the same dataset. Using stepwise regression, Kang and coworkers (2015) presents hip flexion with contralateral trunk bending as the main predictors of the posterolateral reach, explaining 80% of the variance (Kang, Kim, Weon, Oh, & An, 2015). Similar to our study, only the kinematic variables correlated with NRD was used as variables in their stepwise regression model. In our study, for the left foot standing L135 reach, there is a significant trunk flexion, which is not observed in the mirrored reach. One can argue that increased trunk flexion with stance hip flexion helps counterbalance the weight of the reaching leg, thus increasing the dynamic stability, also seen in the investigation by Kang and coworkers (2015). However, as mentioned earlier, the NRD in our study is identical. Additionally, there is a decreased average of approximately 18 degrees of stance hip flexion, 4 degrees of trunk flexion and 12 degrees if knee flexion in right stance foot P180 reach compared to left stance foot P180 reach in our study. Because neuromuscular training is associated with increased reach distance (Filipa, Byrnes, Paterno, Myer, & Hewett, 2010) and because of the identical NRD in these reach directions, the dominant leg demonstrates increased neuromuscular control by reaching the same distance with decreased joint excursion. Therefore, since increased hip flexion does not increase NRD, the true kinematic predictors of the posterolateral reach remain undetected.

4.5 Limitations

There are some limitations to this study. The sample size was relatively low for a stepwise multiple regression analysis, which may compromise the statistical power of our results when comparing to the general population. Additionally, there were more variables analyzed than observed observations (kinematic joint movements compared to subjects) for the stepwise regression analysis, and it may have been subject to overfit, resulting in an over-simplification of the true data model (Roecker, 1991). However, we limited the number of predictors to only four, which were the four highest correlated with NRD or maximum rotation, to account for this limitation. The author of this study recognize the errors occurring associated with investigation movement using retroreflective passive markers together with infrared stroboscopic illumination, such as electronic noise, marker flickering, partially obscured markers, merging- and lost markers (Chiari, Croce, Leardini, & Cappozzo, 2005). Measures to minimize the consequence of these error was made by manual gap filling of marker trajectories and use of 16 cameras with different height and position in the movement laboratory. Additionally, soft tissue artifacts using reflective markers attached to the skin is not without its limitations: the accuracy of skin markers compared to bone markers have previously been evaluated, with a generally poor agreement when measuring frontal and transversal knee motion during running (Reinschmidt, van den Bogert, Nigg, Lundberg, & Murphy, 1997). However, to reduce this error, clusters of markers has been used in this study: this has been shown to reduce the measurement error of using single skin-attached markers only (Leardini, Lorenzo, Croce, & Cappazzo, 2005). The attachment procedure of reflective markers is also subject to error: the anatomical landmarks are not identical points between different participants, inter-subject soft tissue layers are different and identification of anatomical landmarks depends of palpation procedures

(Croce, Leardini, Chiari, & Cappozzo, 2005). To reduce this error in our study, the attachment procedure repeatability was controlled by an experienced clinician to secure correct locations of the reflective markers on all our subjects.

5. Conclusion

The SEBT challenges ankle dorsiflexion and knee internal rotation ROM normative reference values in the anterior reach directions and the medial rotational reach, respectively. The addition of rotational reaches to the classic SEBT does not challenge hip transverse ROM normative reference values as expected. However, they might provide information about rotational dynamic balances and postural control as well as strength. The descriptive kinematics presented in this study may give clinicians valuable insight of the most appropriate reach direction to assess particular joint movements in a closed kinetic chain task, functional joint mobility. Future research should investigate the ability of the new rotational reaches ability to detect hip dysfunction since they do elicit combinations of transverse and frontal joint movements.

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List of Figures

List of Tables

Appendix

Forespørsel om deltakelse i forskningsprosjekt

" Validation of functional mobility screen"

Prosjektet er en del av en doktorgrad ved Norges Idrettshøgskole, og gjennomføres under veiledning av Peter Federolf og Jan Cabri. Prosjektet avsluttes sommeren 2015, men din involvering som forsøksperson vil foregå vår/sommer 2013.

Bakgrunn og hensikt

Tradisjonell mobilitetstesting tester er basert på å isolere ledd og spesifikke bevegelse. Noen tester involverer flere ledd i en kjede, men bevegelsene er da ofte svært lite funksjonelle som eksempelvis en sit and reach test. Det kan derfor tenkes at isolerte og tradisjonelle tester kanskje ikke gir et tilfredsstillende bilde av bevegelsesutslag i leddene ved idrettsrelaterte bevegelser, som ofte forgår stående og involverer flere ledd.

Enhver funksjonell eller atletisk prestasjon handler som samspill mellom ulike ledd i en kjede i alle tre bevegelsesplan hvor det handler om å løse oppgaven på en mest mulig hensiktsmessig måte. Med tanke på mobilitetstesting er det derfor mer hensiktsmessig å teste bevegelsesmønster og ikke isolerte bevegelser, siden disse ikke sier noe samspillet mellom de ulike leddene eller regionene i kroppen.

Vi har derfor utviklet et testbatteri som består av 40 forskjellig tester. Disse testene er basert på grunnleggende bevegelsesmønster som involverer hele kroppen. Testene består av å strekke hender eller føtter i ulike retninger fra ulike startposisjoner. Disse testene er systematisk satt sammen for å kunne beskrive mobiliteten til ulike ledd og regioner i alle tre bevegelsesplan. Tradisjonelle tester for mobilitet av underekstremiteten vil også bli gjennomført for å se hvordan de relaterer til mobilitet i en stående stilling.

Målet med dette prosjektet er å beskrive hvilke bevegelsesutslag og mobiliteten av disse som ligger til grunn for å kunne strekke hender og føtter i ulike retninger. Siden tradisjonelle tester for mobilitet har vist seg å ikke kunne beskrive funksjon i en stående stilling vil en slik studie kunne har stor betydning for utvikling av fysisk prestasjonsevne og brukes som en screen inne skadeforebyggende arbeid. Studien inngår et doktorgradsarbeid ved Norges Idrettshøgskole

Det er ingen spesielle krav i dette studie, bortsett fra at du må være mann frisk og mellom 16 og 40 år uten skader siste 6 måneder som har satt deg ut av trening mer enn 5 dager.

Omfang

Hvis du velger å delta i studien, vil du gjennomgå testene på et tidspunkt som passer for deg. Testingen foregår på laboratorium for bevegelsesanalyse ved Norges idrettshøgskole. Deltagelse i prosjektet vil kreve ca. 3 timer én dag.

Gjennomføring

- Antropometriske data; høyde, arm og beinlengde
- Testing balanse på ett bein på stabilt og ustabilt underlag
- 20 bevegelsesmønster med fokus på strekkebevegelser med hendene i gitte retninger
- 20 bevegelsesmønster med fokus på strekkebevegelser med føttene i gitte retninger
- Tradisjonelle tester mobilitet underekstremiteten

Se vedlegg A for ytterligere detaljer om testene

Fordeler og ulemper ved å delta i studien

Ved å delta i studien vil du få informasjon om din mobilitet ved funksjonelle bevegelsesmønster. Du vil kunne sammenligne din prestasjon på venstre og høyre bein. Når studien avsluttes, vil du kunne sammenligne dine egne resultater med gjennomsnittsverdiene fra alle deltagerne i prosjektet.

Du vil også få verdifull innsikt i hvordan det er å gjennomføre en vitenskapelig studie siden du vil få kjennskap til hvordan man på en meget nøyaktig måte måler hvordan ulike deler av kroppen beveger seg i forhold til hverandre.

Det er noen risikoer forbundet med de ulike testene: det er mulig å strekke seg litt langt i ulike retninger fra noe uvante stillinger. Det vil være en fysioterapeut til stede som kan eksaminere deg i forhold til muskel- og skjelettskader dersom ubehag skulle forekomme.

Det vil bli festet markører til huden din. Dette limet på tapen som brukes kan føre til minimal irritasjon

Målemetoder

Kinematisk analyse

For å registrere hvordan ulike ledd og regioner beveger seg ved de ulike testene benyttes markører som festes til huden din med tape. Du vil få markører festet til foten, leggen, låret, bekkenet, brystkassen, hodet, overarmen, underarmen og hånden. Du må regne meg å bli barbert i et område på 1x1 cm der disse markørene festes.

De ulike testene gjennomføres på en matte hvor man kan lese av centimeter man strekker eller grader man roterer seg i en retning

Krav til deg som forsøksperson

Følgende krav til deg:

- Mann som har fylt 18 år.
- Du kan ikke ha funksjonsforstyrrende muskel-skjelett diagnose i beina og/eller ryggen.
- Du kan ikke ha hatt skade i underekstremiteten i løpet av de siste seks månedene som har satt deg utenfor aktivitet/trening i mer enn 7 dager.
- Du kan ikke noen gang ha vært gjennom rygg, skulder, hofte-, kne- eller fot-operasjon.

Forberedelse til testing

Det er viktig at du har med deg shorts eller en boxershorts siden markørene skal festes til huden på beina, overkroppen og armene.

Din sikkerhet

Det er frivillig å delta, og du kan når som helst trekke deg fra prosjektet uten å måtte oppgi grunn.

Alle data vil bli avidentifisert før de blir lagt inn i en database. Det betyr blant annet at navnet ditt aldri blir nevnt i forbindelse med resultatene. Det vil heller aldri bli gitt opplysninger om hvem som har deltatt i prosjektet. Ved prosjektslutt blir materialet anonymisert. Forskerne er underlagt taushetsplikt og at data blir behandlet konfidensielt. Personopplysninger vil ikke bli utlevert til andre.

Hvis du har lest informasjonsskrivet og ønsker å delta som forsøksperson i prosjektet, ber vi deg om å undertegne ”Samtykke om deltagelse” på neste side og returnere dette til en av personene oppgitt nedenfor. Du bekrefter da at du har fått kopi av og lest denne informasjonen. Du vil få kopi av samtykkeerklæringen.

Prosjektet er meldt til Personvernombudet for forskning (Norsk samfunnsvitenskapelig datatjeneste AS) og det er godkjent av Regional komité for medisinsk forskningsetikk.

Dersom du har spørsmål angående prosjektet, kan du kontakte:
Ola Eriksrud, telefon 97 61 78 93, eller epost ola.eriksrud@nih.no
Fredrik Sæland, telefon +47 93 20 85 44 eller fredriksaeland@gmail.com.

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Ola Eriksrud

Ytterligere informasjon om studien finnes i kapittel ***A*** – *utdypende forklaring av hva studien innebærer.*
Ytterligere informasjon om personvern og forsikring finnes i kapittel B –

Personvern, økonomi og forsikring.

Samtykkeerklæring følger etter kapittel B.

Kapittel A - utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

A: Inklusjonskriterier:

- Fysisk aktiv mann over 18 år

B: Eksklusjonskriterier

- Du kan ikke ha funksjonsforstyrrende muskel-skjelett diagnose i beina og/eller ryggen.
- Du kan ikke ha hatt skade i underekstremiteten i løpet av de siste seks månedene som har satt deg utenfor aktivitet/trening i mer enn 7 dager.
- Du kan ikke noen gang ha vært gjennom rygg, skulder, hofte-, kne- eller fot-operasjon.

Bakgrunnsinformasjon om studien

I denne studien er det mobilitet av ulike ledd og regioner i ulike retninger som er av interesse. Mobilitet er grunnleggende for enhver fysisk prestasjonsevne. Mobilitet måles ofte i dag i mage- eller ryggliggende posisjoner eller sittende. Ett og ett ledd blir målt. Det er ikke slik man beveger seg i det daglige liv eller på idrettsarenaen. Der vil det være et samspill mellom ulike ledd i form av mobilitet. Vi ønsker å teste om ett testbatteri bestående av å strekke hender og føtter i ulike retninger kan gi oss en god representasjon av mobilitet. Sammenhengen mellom hvor langt man strekker seg i ulike retninger og mobilitet har ikke blitt studert på en systematisk måte tidligere.

Hva den inkluderte må gjennomgå

- Antropometriske data; høyde, arm og beinlengde
- Testing balanse på ett bein på stabilt og ustabilt underlag
- 20 bevegelsesmønster med fokus på strekkebevegelser med hendene i gitte retninger. 3 repetisjoner
- 20 bevegelsesmønster med fokus på strekkebevegelser med føttene i gitte retninger. 3 repetisjoner

- Tradisjonelle tester mobilitet underekstremiteten; mageliggende rotasjon hofte innover og utover, Thomas test, Straight leg raise, sittende rotasjon hofte innover og utover, ryggliggende dorsifleksjon og stående dorsifleksjon

Tidsskjema

Rekruttering og testing av forsøkspersoner vil foregå vår/sommer 2013

Mulige fordeler

Man blir bevisst på sin egen evne til å bevege seg i ulike retninger og sin egen mobilitet Dette kan virke skadeforebyggende.

Mulige ulemper

Det er ikke gjort kjent noen mulige bivirkninger, ubehag eller ulemper ved å delta i studien.

Studiedeltakerens ansvar

Ved å delta i studien har du ansvar for å komme til avtalte tider, evt. avlyse i god tid i forveien om oppsatt dato/tid for møtet ikke passer.

Kapittel B - Personvern, økonomi og forsikring

Personvern

Opplysninger som registreres om deg er alder, kjønn, høyde, armlengde, beinlengde, vekt, treningshistorie og fysisk aktivitetsnivå. Opplysningene oppbevares i tråd med Personvernombudet.

Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og prøvene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En tallkode knytter deg til dine opplysninger og testresultater gjennom en navneliste.

Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Når resultatene fra prosjektet er ferdig behandlet og prosjektet er avsluttet, vil navnelistene bli slettet, slik at dine resultater ikke kan spores tilbake til deg. Prosjektet planlegges å avsluttes innen utgangen av 2013.

Andre forskere ved Norges idrettshøgskole vil kunne be om tilgang til det anonyme materialet, til bruk i sammenligning med andre grupper idrettsutøvere eller personer. Norges idrettshøgskole ved administrerende direktør er databehandlingsansvarlig.

Rett til innsyn og sletting av opplysninger om deg og sletting av informasjon

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien kan du kreve å få slettet opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi

Det vil ikke være noen etiske utfordringer knyttet til økonomiens rolle siden Norges Idrettshøgskole finansierer studien.

Forsikring

Staten er selvassurandør

Informasjon om utfallet av studien

Du har rett til å få informasjon om resultatet av studien. Om dette er ønskelig kan du kontakte denne e-postadressen: ola.eriksrud@nih.no desember 2013 og få tilsendt resultatdelen fra studien.

Personvern

Opplysninger som registreres om deg er: Navn, alder, kroppshøyde og resultater fra de beskrevne testene.

Samtykke til deltakelse i studien

Jeg er villig til å delta i studien" Validation of functional mobility screen" og bekrefter å ha lest informasjonsskrivet.

Navn:___________________________

Telefon:_________________________

E-post:__________________________

Signatur:_____________________________________

Sted:____________________Dato:________________

Jeg bekrefter å ha gitt informasjon om studien

____

(Ola Eriksrud, prosjektleder, dato)

Spørreskjema til studien:

"Validation of functional mobility screen"

ID:___________ TEST-DATO:___________ KLOKKEN:___________

1. **Antropometriske data**

Høyde (m)	Vekt (kg)	Skostørrelse	Alder

(Du skal måles og veies her på skolen.)

2. **Aktivitetsnivå** *(Kryss av det som passer best)*

2.1. Hvor mange ganger trener du gjennomsnittlig i løpet av en uke?

	1-2 ganger i uken
	2-3 ganger i uken
	3-4 ganger i uken
	4 -5ganger i uken
	Over 5 – hvor mange?

2.2. Hva består aktiviteten/ene av?

(Den tomme ruten kan du fylle ut om du har drive aktivitet som ikke passer under de andre kategoriene)

Aktivitet	***Skriv hvilken gren/hvilke grener***	***Hvor mange ganger i uken***
Ballspill		
Utholdenhet		
Stryketrening		

3. **Treningshistorie**

3.1. Hvilke aktiviteter har du drevet med tidligere?

(Den tomme ruten kan du fylle ut om du har drive aktivitet som ikke passer under de andre kategoriene)

Aktivitet	***Skriv hvilken gren/hvilke grener***	***Hvor mange år***
Ballspill		
Utholdenhet		
Stryketrening		

4. Skadehistorie

4.1. Har du hatt idrettsskader i løpet av idrettskarrieren din? Hvis svaret er ja, skriv hvilke under. Hvis svaret er nei er du ferdig med spørreskjemaet.
(Den tomme ruten kan du fylle ut om du har hatt skade som ikke passer under de andre kategoriene)

Aktivitet	***Diagnose***	***Hvor lenge satte skaden deg ut av aktivitet?***
Ankel - fot		
Kne		
Hofte		
Rygg		
Skulder		

4.2. Skaden du pådrog deg, var den i venstre, høyre eller begge bein?____________________

4.3. Hvor lenge siden er det du var friskmeldt? ___________________

5. Har du trent i dag?_____________

Hvis du svarte nei på spørsmål 5 er du ferdig med spørreskjemaet. Om du svarte ja skal du svare på 5.1, 5.2 og 5.3.

5.1. Hva har du trent?___________________________

5.2. Hvor lenge varte økten/øktene?_____________________

5.3. Hvilken intensitet trente du på (lav – moderat – høy)?________________________

TAKK FOR AT DU TOK DEG TID TIL Å SVARE PÅ DISSE SPØRSMÅLENE!