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Use of star excursion balance test in assessing dynamic proprioception following anterior cruciate ligament injury

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Abstract
Context: It has been suggested that, with appropriate instruction and practice by the individual and normalization of the reaching distances, the SEBT can be used to provide objective measures to differentiate deficits and improvements in dynamic postural-control related to lower extremity injury and induced fatigue, and it has the potential to predict lower extremity injury. However, literature on its role in assessing proprioception deficits in anterior cruciate ligament deficient knees is limited.
Objective: To provide a narrative review of the SEBT and its implementation and the known contributions to task performance and to systematically review the associated literature to address the SEBT's usefulness as a clinical tool for the quantification of dynamic postural-control deficits from anterior cruciate ligament deficiency.

Keywords: Star excursion balance test, dynamic proprioception, anterior cruciate ligament, postural control, proprioceptive deficit

Introduction

Proprioception and neuromuscular control

Proprioception is defined as the sense of awareness of the joint position. It is achieved by a sensory pathway response triggered by mechanoreceptors found in the synovial joints of the body. The sensory information is transmitted to CNS via afferent pathways which send electric signals through efferent pathways to corresponding muscles surrounding the joint to alter muscle joint tone and function and provide stability [1] The afferent sensory recognition of the joint position and the efferent response to that awareness is referred to as neuromuscular control. It provides the functional component referred to as dynamic stabilization [2].

Measurement of postural control is an important tool in establishing levels of neuromuscular function for injury prevention and rehabilitation. Postural control is described as either static (attempting to maintain a position with minimal movement) or dynamic (maintaining a stable base of support while completing a prescribed movement) [3].

Static postural control assessment is frequently done by modified rhomberg test, first described by Freeman [4]. This test is performed by having participants stand as motionless as possible, on one foot, as a series of task demands are added to challenge the postural control system. These task demands include closing the eyes, tilting the head up, and touching an index finger to the nose. Although this test is commonly used in the assessment of cerebral concussion (bilateral stance) and lower extremity joint injuries (unilateral stance), it typically does not place strength or movement demands on the participant.

Physical attributes such as fundamental movement, mobility, agility, hypertrophy, strength, power and endurance are some of the requirements for athlete. Dynamic postural stability is fundamental to the utilization of many of these attributes, with their effective execution being dependent upon the ability to maintain single leg control with concomitant multi-planar movement demands. Dynamic postural control often involves completion of a functional task without compromising one's base of support. The advantage of assessing dynamic postural control is that additional demands of proprioception, range of motion (ROM), and strength are required along with the ability to remain upright and steady. The Star Excursion Balance Test (SEBT) is one test that provides a significant challenge to an athlete's postural control system [5-8].

The SEBT involves having a participant maintain a base of support with one leg while maximally reaching in different directions with the opposite leg, without compromising the base of support of the stance leg. Earl and Hertel [20] demonstrated the usefulness of the SEBT for the recruitment of lower extremity musculature contraction and discussed its application in rehabilitating various lower extremity musculoskeletal injuries. Researchers have provided evidence that the SEBT is sensitive for screening musculoskeletal impairments, such as chronic ankle instability, quadriceps strength deficits, and patella-femoral pain syndrome. The anterior cruciate ligament deficient (ACLD) subjects who demonstrated a quadriceps strength deficit during isokinetic testing also demonstrated decreased anterior reaching distance while performing the SEBT compared to uninjured matched control subjects.

Proprioception and ACL injury

The occurrence of injury to the Anterior Cruciate Ligament (ACL) is reported to be as high as 46% of all knee ligament injuries in sports [9]. Rupture of the ACL results in antero-lateral instability of the knee which manifests itself as a feeling of instability and repeated episodes of "giving away", where the knee fails under conditions of rotary stress [10]. In the ACL deficient (ACLD) knee, movement occurs in a non-physiological axis, creating alterations in gait and movement [11, 12]. The sensation of instability and giving way that the ACLD patient describes has been attributed to poor proprioception [13] in addition to the actual functional instability. ACL injury has been associated with a resultant decrease in proprioceptive performance due to damage to the mechanoreceptors in the articular structures and the ACL [14].

The ACLD patients showed deficits in their uninjured leg also compared to the control limbs in two of the four directions; medial and lateral directions. Goldie *et al*. [15] previously established that the medial and lateral components of sway were, in their opinion, the best indicators of poor postural sway in relation to ACL injury, and this is further argued by Fridén *et al*. [16] This latter finding may be indicative of a postural control deficit in these patients, which may have predisposed to the ACL injury. If injury to the ACL causes disruption to the mechanoreceptors, causing significantly diminished JPS in the ACLD knee, this could also have a serious effect on postural control. Lack of proprioception may therefore be a contributing factor in preventing adequate motor control to establish satisfactory levels of stability whilst performing such complex movements as those involved in the SEBT. The constant neuromuscular activity required for the fine, but essential, motor adjustments in order to maintain control of the body as a whole is considerable and any disturbance in the feedback from mechanoreceptors may cause errors of judgement that may lead to a lack of postural control. This forms a likely explanation of the differences between the control and ACLD limbs performance. There is an increased risk of injury to the ACL and knee collateral ligaments during cutting tasks, particularly at knee flexion angles of 0-40 degrees, if appropriate muscle activation strategies are not used to counter these increased moments. A decrease in proprioception and kinesthesia occurs after ACL injury. Wojtys and Hutson [25] showed a significant decrease in muscle activation timing and recruitment order in the medial and lateral quadriceps, medial and lateral hamstrings, and gastrocnemius in response to anterior tibial translation in individuals with ACL deficient knees compared with an uninjured control group. The delay in muscle recruitment leads to decreased stability of the joint because the musculature is the primary joint stabilizer owing to loss of ACL function. Also Wilk [26] reported that 24-48 hours after ACL injury, proprioception was altered bilaterally according to measurements on a stability system. The uninvolved extremity was compromised for 6-8 weeks with a gradual improvement in sway balance thereafter.

SEBT Procedure

The SEBT is performed with the participant standing in the middle of a grid formed by eight lines extending out at 45° from each other. (Figure 1). The participant is asked to reach as far as possible along each of the eight lines, make a light touch on the line, and return the reaching leg back to the center, while maintaining a single-leg stance with the other leg in the center of the grid (Figure 2). Participant is instructed to make a light touch on the ground with the most distal part of the reaching leg and return to a double-leg stance without allowing the contact to affect overall balance. The SEBTs are quantified by measuring the distance from the center of the star to the farthest point reached in each direction. The farther the excursion distance the greater the demand on the balance and neuromuscular-control systems. When reaching in the lateral and posterolateral directions, participants must reach behind the stance leg to complete the task. Participant should be allowed to practice reaching in each of the eight directions six times to minimize the learning effect [6]. One should begin with the anterior direction and move clockwise around the grid. After completion of the three trials in the eight directions and 5-min rest period, the test should be continued with a left stance leg. The investigator should record each reach distance with a mark on the tape as the distance from the center of the grid to point of maximum excursion by the reach leg.

At the conclusion of all trials, the investigator measures the distances of each excursion with a standard tape measure. If the investigator feels, the participant used the reaching leg for a substantial amount of support at any time, removed his or her foot from the center of the grid, or was unable to maintain balance on the support leg throughout the trial, the trial would be discarded and repeated. There is a significant learning effect when performing the SEBTs; therefore, at least 6 practice trials are necessary before evaluating a subject's performance.

If the individual touches heavily or comes to rest at the touchdown point, has to make contact with the ground with the reaching foot to maintain balance, or lifts or shifts any part of the foot of the stance limb during the trial, the trial is not considered complete. These stipulations should be applied during rehabilitation, injury evaluation, and research applications of the SEBT. The measurement or outcome from the SEBT performance is how far the participant can reach without violating any of the described stipulations. The reach distance values are used as an index of dynamic postural control (ie, a farther distance reached indicates better dynamic postural-control). These assessments can be compared between injured and uninjured limbs or before and after an intervention to quantify deficits or improvements in dynamic postural-control. The body of literature that exists suggests that, with appropriate instruction and practice by the participant and normalization of the reaching distances, the SEBT can provide objective measures to differentiate deficits and improvements in dynamic postural-control related to lower extremity injury and induced fatigue, and it has the potential to predict injury to the lower extremity

To compare performance within limbs of an individual, comparisons in the absolute reaching distance can be made between reaching distances attained on each limb. However, to make valid comparisons of SEBT reaching distances among individuals or groups, reaching distances need to be normalized to each participant's limb length [17]. This recommendation is based on limb length, as measured from the anterosuperior iliac spine to the medial malleolus, being correlated with reach performance [17]. Whereas overall body height also was correlated with reaching distance, limb length was more strongly correlated [17]. When normalizing reaching distances to limb length, performance typically is expressed as a percentage of limb length.

Discussion

Neuromuscular training is typically used to enhance athlete's preparation, performance and recovery by improving dynamic postural stability [18] which is an integral component of lower limb neuromuscular control. Whereas static measures of postural-control provide useful clinical information, the underlying task of standing as still as possible might not translate necessarily to movement tasks during physical activity. Conversely, dynamic postural-control involves some level of expected movement around a base of support. This might involve tasks, such as jumping or hopping to a new location and immediately attempting to remain as motionless as possible or attempting to create purposeful segment movements (reaching) without compromising the established base of support

The SEBT is a promising test of postural control that may be useful in assessing functional deficits in those with lower-extremity orthopedic injuries. The SEBT requires the individual to move from a double to single-legged stance position while maximally reaching along set multidirectional lines with the opposite leg and touching down lightly on a tape measure with the distal end of the reach foot, without compromising equilibrium [19] These directions have been shown to assess unique elements of postural stability [20] and may be useful in predicting future athletic injury [18]. Completion of the SEBT requires many attributes including strength, flexibility, neuromuscular control, core stability, range of motion, balance and proprioception [21]. Athletes and players undertake open and closed kinetic chain movements utilizing these physical attributes to successfully perform game activities and multi-directional running tasks. Utilizing this test can provide us with objective data for dynamic postural stability evaluation for use in the areas of injury prevention and management, namely assessment, rehabilitation, screening.

The clinician can modify the player's exercise program and progress the intensity and volume of exercise in a safe and effective manner using this test. Improvements in SEBT performance have been observed following the inclusion of neuromuscular training activities [22] and these activities should emphasize sound athletic positioning to help create dynamic control of the athlete's center of gravity in the early stages of rehabilitation [23] The incorporation of the SEBT reaches as controlled functional exercises in lower limb rehabilitation and conditioning programs, may assist in the enhancement of dynamic postural stability and subsequently game related tasks. Utilizing the SEBT as part of a weekly monitoring program may also identify potential injury risk in players developing dysfunction, resulting in early intervention and/or modification of training/competition load Each reaching direction offers different challenges and requires combinations of sagittal, frontal, and transverse movements. The reaching directions are named in orientation to the stance limb as anterior, anteromedial, anterolateral, medial, lateral, posterior, posteromedial, and posterolateral. The goal of the task is to have the individual establish a stable base of support on the stance limb in the middle of the testing grid and maintain it through a maximal reach excursion in one of the prescribed directions [27, 28]. The body of literature that exists suggests that, with appropriate instruction and practice by the participant and normalization of the reaching distances, the SEBT can provide objective measures to differentiate deficits and improvements in dynamic postural-control related to lower extremity injury and induced fatigue, and it has the potential to predict injury to the lower extremity.

Earl and Hertel [20] found that muscle activation, as assessed with surface electromyography, was substantially different across the various reach directions. Vastus medialis activity was greater during the anterior excursion than all other directions. Vastus lateralis activity was less during the lateral excursion than all other directions. Medial hamstring activity was higher during the anterolateral reach direction than during the anterior, anteromedial, and medial excursions. Biceps femoris electromyographic (EMG) activity was higher during the posterior, posterolateral, and lateral excursions than during the anterior and anteromedial excursions [20] The EMG differences across specific reach differences might be helpful to clinicians deciding which reach directions to employ as outcome measures in patients with specific impairments in muscle strength.

Another indication for the use of the SEBTs as a tool is ACL rehabilitation. During conservative and postoperative treatment of ACL-injured knees, the amount of strain placed on the ACL must be limited. Open Kinetic Chain knee extensions place a high amount of shear force on the ACL and could be detrimental. Tibiofemoral compressive forces are greater during Closed Kinetic Chain exercise than during OKC exercise, and hamstring co contraction during CKC knee extension reduces the strain on the ACL. In addition to increased hamstring activity, increased trunk flexion during squatting activities increases the posterior shear force on the tibiofemoral joint [27]. This would be beneficial for early rehabilitation of ACL reconstruction, when CKC exercises are necessary but anterior shear at the tibiofemoral joint must be minimized. Performing anteriorly and medially directed excursions would be an effective way to eccentrically strengthen the quadriceps and improve functional stabilization in the late stages of rehabilitation.

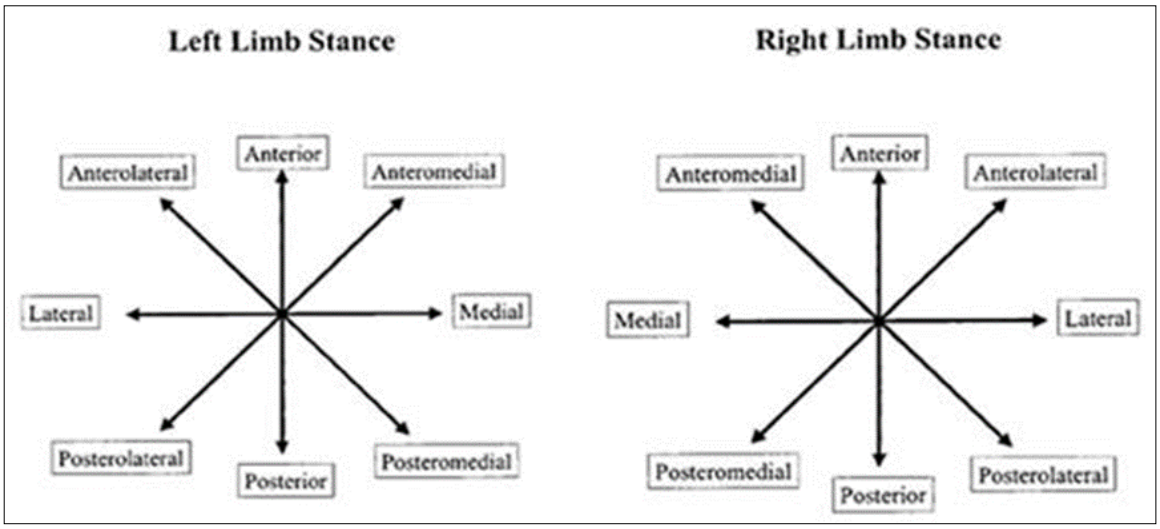

Fig 1: The 8 positions of the SEBT are based on the stance of the affected limb.

Fig 2: Star Excursion Balance Test.

Conclusion

The SEBT is a promising test of postural control that may be useful in assessing functional deficits in those with anterior cruciate ligament injuries. Completion of the SEBT requires many attributes including strength, flexibility, neuromuscular control, core stability, range of motion, balance and proprioception. Utilizing this test can provide us with objective data for dynamic postural stability evaluation for use in the areas of injury prevention and management, namely assessment, rehabilitation, screening.

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