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Kinematic predictors of star excursion balance test performance in individuals with chronic ankle instability

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ABSTRACT

Background: The Star Excursion Balance Test has identified dynamic postural control deficits in individuals with chronic ankle instability. While kinematic predictors of Star Excursion Balance Test performance have been evaluated in healthy individuals, this has not been thoroughly examined in individuals with chronic ankle instability.

Methods: Fifteen individuals with chronic ankle instability completed the anterior reach direction of the Star Excursion Balance Test and weight-bearing dorsiflexion assessments. Maximum reach distances on the Star Excursion Balance Test were measured in cm and normalized to leg length. Three-dimensional trunk, hip, knee, and ankle motion of the stance limb were recorded during each anterior reach trial using a motion capture system. Sagittal, frontal, and transverse plane displacement observed from trial initiation to the point of maximum reach was calculated for each joint or segment and averaged for analysis. Pearson product–moment correlations were performed to examine the relationships between kinematic variables, maximal reach, and weight-bearing dorsiflexion. A backward multiple linear regression model was developed with maximal reach as the criterion variable and kinematic variables as predictors.

Findings: Frontal plane displacement of the trunk, hip, and ankle and sagittal plane knee displacement were entered into the analysis. The final model ($p = 0.004$) included all three frontal plane variables and explained 81% of the variance in maximal reach. Maximal reach distance and several kinematic variables were significantly related to weight-bearing dorsiflexion.

Interpretation: Individuals with chronic ankle instability who demonstrated greater lateral trunk displacement toward the stance limb, hip adduction, and ankle eversion achieved greater maximal reach.

1. Introduction

Chronic ankle instability (CAI) is experienced by approximately 1 in 3 people who sustain an acute ankle sprain (Konradsen et al., 2002). CAI is categorized by recurrent ankle sprain symptoms, repetitive episodes of ankle "giving way," and repeated ankle sprain injuries (Hertel, 2002). Ultimately, many individuals with CAI experience diminished health-related quality of life which may have profound effects on long-term health (Houston et al., 2015). Continuing to advance our understanding of CAI is an important step toward developing innovative treatment strategies to help patients with CAI overcome their health condition.

Many of the aforementioned characteristics of CAI are thought to be linked to sensorimotor impairments which result in functional movement alterations (Hertel, 2008). This has been exemplified by a number of studies which have identified postural control deficits in people with CAI (Arnold et al., 2009). Postural control has been assessed with a number of measurement strategies which range from instrumented static techniques to clinically oriented dynamic techniques such as the Star Excursion Balance Test (SEBT) (Arnold et al., 2009). The SEBT involves unilateral stance while attempting to perform a maximal reach with contralateral limb in a series of reach directions (Gribble and Hertel, 2003; Gribble et al., 2012). Individuals with CAI have typically demonstrated shorter reach distances on this test which indicates dynamic postural control deficits are present (Arnold et al., 2009; Gribble et al., 2012). The SEBT is thought to better represent functional activity over other postural control assessments because it incorporates a combination of strength, flexibility, and neuromuscular control while testing the limits of postural stability (Gribble et al., 2012).

While the validity and reliability of the SEBT have been previously established, this test is interesting in that a theoretically vast number of strategies can be used to execute the movement goal and achieve a similar outcome (Gribble et al., 2012, 2013). This aspect of the SEBT has sparked several investigations with the purpose of examining the kinematics which contribute to the successful execution of this task

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(Fullam et al., 2014; Gribble et al., 2007; Robinson and Gribble, 2008a). In healthy individuals, hip and knee flexion appear to be the dominant kinematics as they accounted for 62–95% of the variance in reach distances when examined across all eight reach directions (Robinson and Gribble, 2008a). This is supported by another study which determined that changes in knee and hip flexion explained 21–59% of the variance in changes in reach distance following fatigue when data were examined in both healthy and CAI participants (Gribble et al., 2007). Finally, a later study determined that ankle dorsiflexion was the greatest sagittal plane contributor to maximal anterior reach distances in healthy participants (Fullam et al., 2014). Therefore, it appears that lower extremity sagittal plane kinematics seem to be the greatest contributors to SEBT performance in healthy individuals.

Fewer studies have examined the kinematics incorporated into SEBT performance in people with CAI. A recent study (de la Motte et al., 2015) determined that individuals with CAI utilized greater amounts of trunk rotation, pelvic rotation, and hip flexion at the point of maximal reach compared to healthy individuals despite observing no significant differences between groups in any reach distances. This study (de la Motte et al., 2015) demonstrated that individuals with CAI may utilize different movement strategies which may be more reliant on non-sagittal plane motion to execute the movement goal. One potential explanation why individuals with CAI may adopt frontal or transverse plane strategies is because of restrictions in ankle dorsiflexion range of motion (RoM) which is commonly identified in these patients (Hoch et al., 2012b). Individuals with CAI have concurrently demonstrated decreased weight-bearing dorsiflexion ROM and shorter reach distances on the SEBT (Hoch et al., 2012b). This relationship has been most defined in the anterior reach direction based on multiple studies which have identified a moderate positive relationship between these assessments (Basnett et al., 2013; Gabriner et al., 2015; Hoch et al., 2012b; Terada et al., 2014). Determining if dorsiflexion RoM contributes to altered movement strategies may be an important factor in restoring preinjury movement patterns.

Despite the research to this point, the kinematic predictors of SEBT reach distances in individuals with CAI remain unclear. Additionally, it is uncertain how weight-bearing dorsiflexion RoM influences kinematics patterns during SEBT performance. Therefore, the primary purpose of this study is to identify the kinematic predictors of the anterior reach distances of the SEBT in people with CAI. The secondary purpose of this study is to examine the relationships between weight-bearing RoM, anterior reach distance, and the kinematics utilized during SEBT performance. We hypothesize that anterior reach distances will be significantly predicted by non-sagittal plane kinematic variables and weight-bearing dorsiflexion RoM will be significantly correlated to anterior reach distance and several kinematic variables captured during SEBT performance.

2. Methods

2.1. Participants

Fifteen physically active individuals with CAI (10 females, 5 males, 21.9 (2.1) years, 69.4 (13.3) kg, and 1.68 (0.09) m) participated in this cross-sectional study. The International Ankle Consortium's position statement on selection criteria for patients with CAI was used to guide subject inclusion (Gribble et al., 2014). All participants reported a history of ≥1 significant ankle sprain (2.7 (2.4)) and >1 episode of “giving way” in the previous 3 months (4.9 (5.5)). Participants also had to answer affirmatively to ≥4 items on the Ankle Instability Instrument (Docherty et al., 2006) (6.3 (1.5)) and report at least moderate levels of physical activity (≥4) on the NASA Physical Activity Scale (6.1 (1.8)) (Wier et al., 2001). Additionally, participants completed the Foot and Ankle Ability Measure Activities of Daily Living (90.6 (5.4%)) and Sport (79.0 (12.5%)) (Martin et al., 2005). Participants were excluded if they experienced an ankle sprain in the 6 weeks prior to the study, had a history of lower extremity fracture or surgery, sustained any other lower extremity injuries in the past 6 months, or reported any other conditions which may affect postural control. If a subject reported bilateral ankle instability, the limb with the lower FAAM scores was used for testing. All participants provided written informed consent in compliance with the University's institutional review board.

2.2. Procedures

Participants reported to the laboratory for a single testing session and performed the weight-bearing lunge test (WBLT) and the anterior reach direction of the SEBT on the involved limb. Participants were outfitted with retro-reflective markers for tracking motion during the anterior reach task after completing the WBLT. Participants wore spandex shorts, no shirt for men and a sports bra for women, and low-cut socks in order to accurately capture motion analysis data. Participants also wore Nike sneakers (Air Max Glide, Nike, Beaverton, OR, USA) provided by the investigators and were fitted to each individual in either men's or women's sizes.

Maximum weight-bearing ankle dorsiflexion RoM was assessed using the WBLT knee-to-wall principle (Hoch and McKeon, 2011). This assessment technique required participants to perform a series of lunges while facing a wall. During each lunge, the ability of the anterior knee to make contact with the wall and the heel to remain in contact with the ground was assessed on the involved limb. Provided the anterior knee made contact with the wall and the heel remained planted on the floor, the participant was gradually progressed backwards. Maximum lunge distance (cm) was determined as the farthest distance (tip of the great toe to the wall) in which both criterion could be maintained (Hoch and McKeon, 2011). Three trials were performed for each participant and averaged for analysis.

Upon completion of the WBLT, participants were prepared for motion capture by applying retro-reflective markers bilaterally over the following locations using double-sided tape for standing calibration: acromioclavicular joint, ASIS, PSIS, iliac crest, greater trochanter, lateral and medial femoral condyles, lateral and medial malleoli, base of the fifth metatarsal, and base of the first metatarsophalangeal joint (Weinhandl and O'Connor 2010a). Cluster plates composed of four markers were attached to the heel of the shoe and the lower leg, thigh, and mid-thoracic region on the back. An 8 camera motion analysis system (Vicon Motion Systems, Denver, CO, USA) collected kinematic data at 200 Hz. Participants were instructed to stand and raise their arms for calibration. Following calibration, all markers except the ASIS, PSIS, and cluster plates were removed for dynamic motion capture.

The anterior reach direction of the SEBT was measured on the involved limb for all participants (cm). The anterior reach direction was selected because individuals with CAI have demonstrated kinematic differences in a similar reach direction in previous research (de la Motte et al., 2015). Participants performed four practice trials, followed by three test trials (Robinson and Gribble, 2008b). All participants were positioned with their foot centered in the middle of the testing grid and aligned with a tape measure secured to the floor. Participants were verbally instructed to perform maximal reaches with the uninvolved limb, followed by a single, light toe touch on the tape measure, while maintaining a single limb stance with their hands on their hips. In the event of an error, trials were discarded and repeated. Errors included lifting hands from the hips, the position of the stance foot was not maintained, the heel did not remain in contact with the floor, the toe-touch was prolonged or heavy, or the participant lost balance during the trial (Gribble and Hertel, 2003). The test trials were averaged and normalized to leg length (MAX%) for analysis.