The Relationship between Chronic Ankle Instability and Functional Movement Impairment in Division I Female Athletes

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THE RELATIONSHIP BETWEEN CHRONIC ANKLE INSTABILITY AND FUNCTIONAL MOVEMENT IMPAIRMENT IN DIVISION I FEMALE ATHLETES
THE RELATIONSHIP BETWEEN CHRONIC ANKLE INSTABILITY AND FUNCTIONAL MOVEMENT IMPAIRMENT IN DIVISION I FEMALE ATHLETES

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Kinesiology

By

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ABSTRACT

Lateral ankle sprains are the most common injury in athletics (Denegar & Miller, 2002; Ekstrand & Tropp, 1990). In addition, the recurrent rate of ankle sprains is as high as 80% (Smith & Reischl, 1986). Repetitive ankle sprains may lead to a phenomenon known as chronic ankle instability (Hertel, 2002). It has been theorized that there are two main attributions to chronic ankle instability: mechanical and functional instability (Monaghan, Delahunt, & Caulfield, 2006). The exact mechanism of chronic ankle instability is still unclear; however, recent studies focus on multiple factors rather than single measurements, in addition to functional testing. A few studies showed the validity of the use of functional movement screen to predict injury risk (Kiesel, Plisky, & Butler, 2007; Chorba, Bouilon, Overmyer, & Landis, 2010), however there is limited research concerning past injury history and movement impairment. Therefore it was the purpose of this study to use functional movement screen to determine if participants with chronic ankle instability exhibit notable functional movement impairments when compared to a group of matched control with no lower extremity injury history.
This thesis is approved for recommendation to the Graduate Council.

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DEDICATION

I would like to dedicate this thesis to my family in Japan and all my mentors in the states. Thank you for all of the love and support you have shown me while I am away from the home country.
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CHAPTER 1
INTRODUCTION

Lateral ankle sprains are the most common injury in athletics (Denegar & Miller, 2002; Ekstrand & Tropp, 1990). Following injury to the lateral ankle complex, initial efforts to control the inflammatory response are essential (Prentice & Hunter, 1999). Immediate care is necessary to reduce the negative sequela following injury while allowing for early rehabilitation. However, there is a tendency for interventions to focus on relief from acute symptoms, such as pain, to be immediately followed by full return to activity while the ankle is still at risk for re-injury (Denegar & Miller, 2002). Since the ankle joint is the most congruent joint in human body, the athlete may have a false sense of security despite the presence of joint laxity. Early return to activity is common despite reports that the recurrent rate of ankle sprains is as high as 80% (Smith & Reischl, 1986). Repetitive ankle sprains may lead to a phenomenon known as chronic ankle instability (CAI) which is the occurrence of repetitive bouts of ankle sprains, feeling of instability or “giving way”, and persistent symptoms (Hertel, 2002). The mechanism for the development of CAI is still unclear, however, it has been theorized that there are two main attributions: mechanical ankle instability (MAI) and functional ankle instability (FAI) (Monaghan, Delahunt, & Caulfield, 2006).

Mechanical ankle instability is joint laxity following an ankle sprain and affects joint accessory movement (Hertel, 2002). Hypermobility of the ankle joint may alter proprioception by increasing stress on the mechanoreceptors in the joint structures, such as ligaments and joint capsule. If initial hypermobility is not properly addressed, accessory motion will likely become restricted (Hubbard & Hertel, 2006). Hypomobility affects physiological movements in the ankle joint such as decreased dorsiflexion (Denegar & Miller, 2002). In addition, compensatory
movements of surrounding joints may occur in order to restore the normal physiological movement (Soavi et al., 2000). In return, the compensatory movement puts abnormal tension on joint mechanoreceptors, thus affecting the joint’s afferent response. Functional ankle instability is a repetitive episode of “giving way” without actual joint laxity (Tropp, 1986). Several factors may contribute to the development of FAI, such as reflex latency and strength deficits (Konradsen, Olsen, & Hansen, 1998). However, current literature suggests that FAI is the result of reduced proprioceptive and neuromuscular control following injury to the ankle joint (Hertel, 2000).

Local strength and range of motion (ROM) of the ankle joint have been typically studied in patients with CAI (Hubbard & Hertel, 2008; Konradsen, Olesen, & Hansen, 1998). However these studies were limited in that they focused only on the ankle joint. Since lateral ankle sprains occur in more dynamic motion, it may appear that testing which involves multiple body segments and requires more functional rather than isolated task seems more preferred in order to see the comprehensive mechanism of CAI.

Grey Cook introduced Functional Movement Screening (FMS), which is aimed to determine potential injury risk by evaluating seven fundamental movement patterns (Chorba, Bouillon, Overmyer, & Landis, 2010). Functional movement screening challenges an individual’s stability, mobility, and balance simultaneously (Chorba, Bouillon, Overmyer, & Landis, 2010). The FMS oversees movement patterns rather than individual measurements such as strength and ROM of each body part (Minick, Kiesel, Burton, Taylor, Plisky, & Butler, 2010). Functional movement screening emphasizes whole movement patterns because dysfunction in one body part may affect other regions indirectly, known as regional interdependence (Wainner, Whitman, Cleland, and Flynn, 2007).
Recently, there has been validation of the FMS score (Kiesel, Plisky, & Butler, 2007; Chorba, Bouillon, Overmyer, & Landis, 2010). These studies revealed a notable relationship between injury risk and FMS score. More specifically, the individuals who scored low in FMS testing, less than 14 out of 21, had a greater chance of sustaining an injury in the competition season. These results indicate that movement impairment is a good indicator of potential injury. Injury history is also considered one of the strongest risk factors of injury (Cook, 2010). If both movement impairment and injury history are injury risk factors, a connection between these two factors may be inferred. Currently, a limited number of studies have investigated the relationship between past injury and movement impairment.

**Statement of the Problem**

The purpose of this study was to use FMS to determine if participants with CAI exhibit notable functional movement impairments when compared to a group of matched controls with no lower extremity injury history.

**Hypotheses**

The hypotheses for the study presented stated:

1. The total FMS score in participants with CAI will be significantly lower than the FMS scores in a healthy control group.
2. The mean scores of each test will be significantly different between CAI and control group.
3. In tests with unilateral movement, the mean scores of injured side in CAI group will be significantly lower than the mean scores of matched side in the healthy group.
4. The mean scores of higher movement and stability movement in CAI will be significantly lower than the mean scores of healthy group.
Significance of the Study

Few researches have examined multiple body segments, which involve functional movement patterns with participants with CAI. Majority of researches focused on local ROM, strength and balance. Since lateral ankle sprains occur in more dynamic motion, using FMS test was thought to give a different angle to look at the mechanism of CAI.

One of the fundamental concept of FMS is that dysfunction in one body part may indirectly affect another body part (Wainner, Whitman, Cleland, and Flynn, 2007). Repetitive trauma to the ankle joint due to CAI may affect neuromuscular activation of other body parts. Retraining muscular activation patterns at the remote areas may have a positive effect to rehabilitate CAI. Therefore, the relationship between CAI and movement impairment might be a beneficial addition to the current CAI prevention and intervention literature.

Assumptions

1. Researchers assumed that each participant would perform honestly and to his or her trust ability.
2. Researchers assumed that each participant can compete at the collegiate level.
3. Researchers assumed that each participant was free of injury for at least six weeks prior to the testing.
4. Researchers assumed that each participant was representative of the fitness level required for collegiate athletes.

Delimitations

This study was delimitated to Division I female collegiate athletes.
Chapter 2
LITERATURE REVIEW

Chronic Ankle Instability Mechanism

Repetitive ankle sprains may lead to a phenomenon known as chronic ankle instability (CAI). CAI has been defined as the occurrence of repetitive bouts of ankle sprains, feeling of instability or “giving way”, and persistent symptoms (Hertel, 2002). The exact mechanism of CAI development is still unclear. However, researchers suggest that there are two main contributions to CAI: mechanical instability and functional instability (Hubbard & Hertel, 2008).

Mechanical Instability

Mechanical instability is a pathological laxity resulting from tearing or lengthening of ligaments in a joint (Hertel, 2002). A potential implication of pathological laxity is gross joint instability resulting from increased range of motion (Hubbard & Hertel, 2002). Increased joint instability accompanies the change in joint accessory motion following an injury (Hertel, 2002). Accessory joint motion is referred to as arthrokinematics (Hougrum, 2005). Arthrokinematics occurs between bones that form a joint and cannot be controlled by conscious effort. Two common mechanical changes in accessory motion are hypermobility and hypomobility (Hubbard & Hertel, 2002); these abnormal accessory movements may result in physiological joint movements (Loudon & Bell, 1996).

Hypermobility of accessory motion occurs due to a tear or elongation of ligaments following an injury (Leardini, O’Connor, Catani, & Giannini, 1999; Panjabi, 1992). Increased intra-articular movement may create additional tension on previously damaged ligaments. Consequently, the excessive accessory motion causes the damaged ligament to be healed in an elongated position (Denegar & Miller, 2002). In addition, increased accessory motion may create
secondary damages to the surrounding intact tissues. If elongation of ligaments is maintained, tension for a given angle of joint position would be reduced, thus affecting the joints mechanoreceptors (Wilkerson, 1994; Konradsen, 2002). Subsequently, mechanoreceptors could misinterpret the degree of motion angle due to an increased threshold to detect the position sense and motion (Konradsen, Olesen, & Hansen, 1998). Altered proprioceptive input following arthrokinematic changes may in fact create more negative effects in a long term on joint stability than the laxity itself (Hertel, 2002).

Hypermobility at the talocrural joint has been typically observed following a lateral ankle sprain (Nitz, Dobner, & Kersey, 1985). The anterior talofibular ligament (ATFL) is reported to be the weakest and most commonly injured ligament in the ankle joint (Hertel, 2002). The talus mostly depends on the ATFL for stability due to the lack of muscular attachments (Denegar, Hertel, & Fonseca, 2002). Therefore, the talus is susceptible to the development of abnormal accessory motion following damage to the ATFL. More specifically, the talus may exhibit anterolateral rotary instability, which is defined as excessive anterior transition and internal rotation of the talus from the mortise (Nits, Dobner, & Kersey, 1985).

Hypermobility may also occur at the subtalar joint following a lateral ankle sprain (Martin, Wayne, Monahan, & Adelaar, 1989). There are two main ligaments that maintain the integrity of the subtalar joint: interosseous and cervical ligaments (Konradsen, Voigt, & Hojsgaard, 1997). These two ligaments are referred to as the “cruciate ligament” of the ankle joint and prevent excessive movement in the frontal plane along with the assistance of the calcaneofibular ligament (CFL) (Viladot, Lorenzo, Salazar, & Rodriguez, 1984). It has been reported that 75% to 80% of individuals with CFL injury also had damage to the subtalar ligaments (Martin, Wayne, Monahan, & Adelaar, 1998). Despite the relatively high incidence of
subtalar instability, athletes often return to activity without any support to the subtalar ligaments (Denegar & Miller, 2002).

If initial hypermobility is not addressed through rehabilitation, joint accessory motion may become hypomobile, with restriction of normal arthrokinematics (Hubbard & Hertel, 2006). The talus and the distal fibula seem to exhibit hypomobility following lateral ankle sprains (Hubbard & Hertel, 2008). Denegar, Hertel, and Fonseca (2002) reported the significant arthrokinematic impairment of the talus in the injured leg in comparison to the uninjured leg in participants with a history of unilateral ankle sprains. Characteristically, the swollen ankle tends to splint itself in slight plantar flexion because of the effect of gravity and the effort to minimize pressure inside the joint (Wilkerson & Nitz, 1994). Since plantar flexion of the foot is accompanied by an anterior glide of the talus, posterior glide of the talus may be impaired if the foot is immobilized in the plantar flexion position (Loudon & Bell, 1996).

Hubbard and Hertel (2008) introduced the positional fault of the distal fibula. They suggested that anterior transition of the distal fibula may occur following inversion ankle sprains. It is also reported that participants with more swelling had greater anterior displacement of the distal fibula. Therefore, excessive and prolonged swelling may contribute to anterior transition of the distal fibula after the lateral ankle sprain.

Impairment of accessory motion, especially hypomobility of the talus and the distal fibula, may result in the altered physiological movement, such as decreased dorsiflexion range of motion (ROM) (Denegar & Miller, 2002). At the talocrural joint, the talus articulates with the mortise which is composed of distal tibia and fibula. The talus is wide anteriorly and convex shaped, while the mortise is concave in nature on the talocrural joint. The direction of the accessory motion of the convex surface is opposite to the physiological movement (Hougrum,
2005). Therefore, the convex talus moves anterior to posterior when the foot moves into
dorsiflexion in the talocrural joint (Soavi et al., 2000). This accessory movement of the talus
accompanies movement of the distal fibula (Loudon & Bell, 1996). The distal fibula must glide
superiorly and displace laterally to accommodate the wide portion of the talus when the foot
moves into dorsiflexion (Loudon & Bell, 1996). If the talus and fibula are not able to glide
normally, the articular surface inside the joint collide into each other, thus decreasing
dorsiflexion. Decreased dorsiflexion has been thought to be the major risk factor of the lateral
ankle sprain during gait cycle since the ankle joint is less stable in plantarflexion (Hertel, 2002).

It is important to note that the range of dorsiflexion may appear normal in some
individuals in spite of the presence of restricted accessory movement. Denegar, Hertel, and
Fonseca (2002) found limited posterior glide of the talus among the participants with a history of
lateral ankle sprains. Opposite to their hypothesis, there were no significant differences in
dorsiflexion range of motion between the injured leg and the uninjured leg. The possible
explanation is the development of altered instantaneous axis of rotation, which creates
compensatory movement patterns at surrounding joints. With the proper mobility of accessory
movements of the talus and distal fibula, the talus and the mortise glide within the joint, while
the instantaneous axis of rotation adjusts accordingly (Soavi et al., 2000). If the accessory
movements at the ankle joint are impaired, the normal movement pattern of instantaneous axis of
rotation will be altered (Soavi et al., 2000). Specifically, if the talus lacks posterior glide in
dorsiflexion, the instantaneous axis of rotation will become slightly anterior (Sammarco,
Burstein, & Frankel, 1973). This abnormal instantaneous axis of rotation may enable the
talocrural joint to regain the full dorsiflexion range of motion. In return, it creates compensatory
movements at surrounding joints of the foot. The compensatory movements may abnormally stress the surrounding joint structures, such as mechanoreceptors (Wilkerson & Nitz, 1994).

**Functional Instability**

There is a lack of evidence that functional instability and mechanical instability exists together. However, it has been suggested that these two factors are linked to each other since alternation in arthrokinematics could affect proprioceptive input (Hertel, 2002). Functional instability is defined as the occurrence of joint instability sensation, which is often referred to as “giving way” without the presence of joint laxity (Tropp, 1986). Traditionally, it was believed that functional instability may be caused by insufficiencies in reflex response and strength deficit of an evertor muscle group against sudden inversion protuberance (Konradsen, Olsen, & Hansen, 1998).

According to Freeman, Dean, and Hanham (1965), dynamic stability against lateral ankle sprains is achieved by the quick reflex response of concentric contraction of the evertor muscles. Thus the author assumed that the individuals with functional instability exhibit a delayed reflex response due to altered afferent input from mechanoreceptors following an ankle injury (Freeman, Dean, & Hanham, 1965). However, other researchers suggest that the reflex latency may not be the primary cause of ankle instability. Konradsen, Olesen, and Hansen (1998) reported that the reaction time of evertor muscles in injured legs among the CAI group was unchanged compared to the contralateral legs at three and six weeks post injury. Another study injected a lidocaine solution into the lateral ligaments of the ankle among the participants who did not have any history of lower extremity injuries in the past (Myers, Riemann, Hwang, & Fu, 2003). Opposite to their hypothesis, researchers concluded that anesthetic effects to lateral ankle ligaments did not change muscle reflex latency. These studies indicate that the initial acute
damage to lateral ankle structures does not significantly change the reflex reaction time of
evertor muscles. In addition, it is reported that it takes at least 126 milliseconds for evertor
muscles to respond to the sudden inversion force in a healthy ankle (Konradsen, Voigt, &
Hojsgaard, 1997). Since inversion may occur in as little as 40 milliseconds after the initial
contact, it is suggested that reflex response of evertor muscles alone is not fast enough to prevent
sudden ankle perturbation (Ashton-Miller, Ottaviani, & Hutchinson, 1996). Therefore, reflex
latency may not be a sufficient explanation for the mechanism of functional instability (Beckman
& Buchanan, 1995).

Strength deficit of the peroneals has been suspected another cause of functional
instability (Konradsen, Olsen, & Hansen, 1998). An early study found weakness in ankle evertor
muscles among the CAI group and concluded that strong concentric contraction of evertor
muscles are required to combat inversion forces (Tropp, 1986). Notwithstanding, there is an
opposite outcome when observing muscle weakness after ankle injury. A study reported that the
evertor muscle strength is not different between the injured and uninjured leg of participants in
the CAI group (Wilkerson, Pinerola, & Caturano, 1997). Also, evertor muscle strength among
the CAI group was not significantly different from the control group. Konradsen, Olsen, and
Hansen (1998) detected significant decrease in evertor muscle strength after acute ankle sprains.
However, it was noted that decreased strength of evertor muscles was successfully restored to
that of the uninjured leg six weeks following initial injury. The fast recovery indicates that even
though muscle weakness may exist to some degree, it may not be a long term deficit. Although
controversy exists, evidence of strength deficit in evertor muscles is not sufficient to support the
theory that it solely contributes to the development of functional instability. Recently the role of
eccentric contraction of invertors to prevent excessive inversion force has gained more attention
(Wilkerson & Nitz, 1994). Though it requires more supporting evidence, eccentric inversion contraction may play an important role in deceleration of lateral displacement of foot following the initial heel contact. Therefore, it is rational to mention that dynamic ankle stability is achieved not only by strong concentric contraction of evertors but also by coordinated muscle contractions of various muscles around the ankle joint (Kaminski, Hartsell, 2002).

As discussed above, it appears that protective mechanisms against inversion sprains may not be a simple reflex latency and strength deficit of one muscle group (Gertel, 2002). A more recent trend suggests that functional instability is caused by the deficits or altered function of proprioception and neuromuscular control (Hertel, 2000). Neuromuscular control relies on afferent information from mechanoreceptors in joint structures and ligaments (Riemann & Lephart, 2002). Proper communication between afferent and efferent input is essential to control precise physiological joint motion. Therefore, damage to mechanoreceptors following an ankle sprain may affect the ability of mechanoreceptors in the ankle joint to send proper afferent input which further affects the neuromuscular activation.

Mechanoreceptors are responsible for joint motion detection and position sense (Konradsen, 2002). Since afferent information from the ankle joint is primarily elicited by mechanoreceptors, it has been hypothesized that proprioceptive function may be altered by damage to mechanoreceptors secondary to ankle injury. Konradsen, Olesen, and Hansen (1998) assessed position sense of the ankle joints among uninjured and CAI group. Participants’ ankles were passively moved to the inversion position and then returned to the neutral position. Participants were asked to actively reproduce the initial inversion position. Results revealed reproduction error of the injured leg was doubled when compared to the uninjured side among the CAI group. In addition, no bilateral differences were noted among participants without
history of an ankle injury. Furthermore, the position reproduction error among the CAI group was present even after 12 weeks; it indicates that joint position sense may be significantly altered after an ankle injury. With a limitation being that position sense was in an open kinetic chain. Since functional instability occurs in activities such as walking or running, it is necessary to note if joint position error also exists in a closed kinetic chain.

A study measured ankle position sense during gait cycle (Delahunt, Monaghan, & Caulfield, 2006). The investigators reported that participants with CAI demonstrated an increased inverted foot position early during the stance phase of gait cycle, predominantly before and after heel strike. Participants with functional instability had an increased inverted foot position during the terminal swing phase. The ankle of CAI participants may move further into inversion than the uninjured ankle due to the increased threshold to detect movement and position. Since excessive inversion of the foot at initial heel contact may increase the magnitude of external load on the ankle joint, this positional fault may have a positive correlation with potential inversion injury. Supination during preswing phase is necessary to act as a rigid lever and create sufficient tension between articulations of forefoot (Wilkerson, 2002); however, excessive inversion at the preswing phase may increase chances of a lateral inversion sprain due to close proximity of the lateral border of the foot to the ground (Winter, 1987).

It appears that proper proprioception from mechanoreceptors to detect joint position and movement is essential in both open and closed kinetic chain activities (Monaghan, Delahunt, & Caulfield, 2006). It is important to note that altered joint position is not solely caused by a deficit in afferent input. Since dynamic muscular activity controls the foot position, proper efferent input to the joint is also essential (Southerland, 2001). A study observing a neuromuscular activity of muscles around the ankle joint found an abnormal firing pattern of peroneus longus
muscle during the stance phase in CAI participants and healthy participants who had fluid injection to ATFL and CFL (Myers, Rienmann, Hwang, Fu, & Lephart, 2003).

Exact mechanism of altered neuromuscular activation following damage to the mechanoreceptors is still unclear (Hertel, 2002); however, McVey, Palmieri, Docherty, and Zinder (2005) measured the motor neuron excitability and found motor neuron inhibition of the peroneus longus. It was hypothesized that the motor neuron inhibition could be the result of arthrogenic inhibition. Arthrogenic muscle response is defined as “an ongoing reflex reaction of musculature surrounding a joint after distension or damage to the structure of the joint” (Hopkins & Ingersoll, 2000). Arthrogenic muscle inhibition of the quadriceps muscle after knee injury has been recognized and associated with joint effusion (Ekholm, Eklund, & Skoglund, 1960). Myer, Riemann, Hwang, Fu, and Lephart, (2003) observed decreased neuromuscular amplitude among the uninjured participants with injection of either placebo or lidocaine into the ATFL and CFL. The outcome of this study indicated that the injection of both solutions resulted in altered neuromuscular activation. Therefore, it was concluded that the increase in articular pressure due to swelling may cause the arthrogenic muscle inhibition.

In addition to the altered neuromuscular activation of peroneus muscles, Beckman and Buchanan (1995) investigated that neuromuscular activation of proximal body parts, primarily hip abductors, following ankle injury. The ankle joint plays a primary role in maintaining balance against lateral sway (Friel, McLean, Myers, & Caceres, 2006). The amplitude of lateral sway increases when the ankle is unable to maintain balance (Levangie & Norkin, 2001). Beckman and Buchanan (1995) observed the decreased latency of hip abductor activation. Findings confirm that participants with a history of ankle sprains recruit hip abductors significantly earlier than the control group in order to compensate for the decreased ability of the
ankle joint to maintain balance. However, despite this compensation (Hertel, 2002), hip abductor muscles may exhibit weakness following ankle injuries (Friel, McLean, Myers, & Caceres, 2006). As a result of hip abductor weakness, it is unlikely that the hip strategy is able to fully compensate function of the ankle joint.

**Measurement**

Early studies focused on range of motion and strength measurements at only the ankle joint in CAI group. However, arthrokinematics impairment, either hypermobility or hypomobility, may create abnormal physiological movements at both local and peripheral joints; thus damaging mechanoreceptors. Dynamic ankle stability is achieved not only by a strong concentric contraction of the evertor muscle group but by the coordinated muscle contractions of various muscles surrounding the ankle joint. Moreover, altered sensory input may affect neuromuscular activation at more proximal levels as well as the ankle joint after lateral ankle sprains (Hertel, 2002). Therefore, assessment of multiple body segments requiring more functional rather than isolated task seems more beneficial in order to determine the comprehensive mechanism of CAI.

**Functional Testing**

Static balance tests have been commonly used to measure balance deficits. Postural balance requires a combined effort of proprioception and neuromuscular control as well as basic range of motion and strength of each joint (Delahunt, 2007). If impairment occurs at any component following ankle injury, it will theoretically affect the postural balance as a whole. The research assumed that CAI individuals may exhibit balance deficits. However, results are inconsistent when measuring the balance deficits in CAI participants using static balance tests. Delahunt (2007) suggested that static balance testing may not be sensitive enough to detect
balance deficits. Type III mechanoreceptor, which is widely seen in the human ankle joint, is active only at the end range of motion (Hogervorst & Brand, 1998). Static balance tests may not activate this kind of mechanoreceptors and may not be sensitive enough to detect the deficits in postural balance. Therefore, dynamic balance tests seem more challenging and sensitive enough to detect the balance deficits (Hertel, 2002), since ankle instability typically occurs in functional activities.

The Star Excursion Balance Test (SEBT) has been introduced as a dynamic balance test (Olmsted, Garcia, Hertel, & Shultz, 2002). Dynamic postural stability has been defined as “the extent to which a person can lean or reach without moving the feet and still maintain balance.” Individuals are asked to reach as far as they can in eight directions while maintaining a balance on the opposite leg. The task requires adequate ROM, strength, proprioception, and coordinated neuromuscular control in dynamic movement, thus demanding more functional tasks on the injured ankle. The researchers reported that participants with CAI reached significantly less while standing on their injured leg than uninjured legs. Also, the CAI group demonstrated less reach than the control group. Thus, SEBT seems to be a valid measurement to detect individuals with CAI. The use of SEBT is beneficial to clinicians due to low cost, convenience, and high validity of detecting dynamic balance deficit in CAI group.

Functional Movement Screening

Gray Cook introduced Functional Movement Screening (FMS), a method used to determine potential injury risk by evaluating seven fundamental movement patterns (Chorba, Bouillon, Overmyer, & Landis, 2010). The seven movement patterns consist of a deep squat (DS), hurdle step (HS), in-line lunge (ILL), shoulder mobility (SM), active straight leg raise (ASLR), push up (PU), and rotary stability (RS) (Cook, 2010). DS, HS, and ILL are considered
to be higher level movements since they require both mobility and stability in the three essential foot positions humans experience every day. The other four tests are primitive movement patterns representing mobility (SM and ASLR) and stability (PU and RS).

The FMS challenges an individual’s stability, mobility, and balance simultaneously (Chorba, Bouillon, Overmyer, & Landis, 2010). One of fundamental concepts of FMS comes from the theory known as regional interdependence (Minick, Kiesel, Burton, Taylor, Plisky, & Butler, 2010). According to Wainner, Whitman, Cleland, and Flynn (2007), dysfunction in one body part may indirectly affect other regions. Myers (2009) stressed the importance of fascial continuity in the human body; stating that the tensile force from one joint is transmitted throughout the body by connective tissues. Lower leg muscles such as the tibialis anterior and peroneus longus directly controls the ankle joint motions. Conventional anatomical explanation displays muscle origin and insertion, which may appear that each muscle is separated from the other. However, the author suggested that the tibialis anterior and peroneus longus are part of the “spiral line” fascial connection and linked up to the skull in a double spiral fashion. Since the spiral line is responsible for maintaining balance, dysfunction at one segment may create secondary effect on either proximal or distal segments.

Recently, few studies have addressed the validity of FMS (Kiesel, Plisky, & Butler, 2007; Chorba, Bouillon, Overmyer, & Landis, 2010). One study conducted FMS testing in pre-season as a pre-season performance test in an NFL team (Kiesel, Plisky, & Butler, 2007). A player was considered injured if he was on the injured reserve or absent from practice or a game for more than three weeks during the following NFL regular season. The investigator found significant differences in the total scores of FMS between injured (14.3) and uninjured player (17.4). The researcher determined that 14 as a cutoff point was appropriate. Players who scored less than 14
had a 51% probability of suffering an injury in season. In other words, NFL players with lower scores were more likely to get injured during the competition season. Another study conducted FMS testing on 38 NCAA Division II female collegiate athletes during preseason (Chorba, Bouillon, Overmyer, & Landis, 2010). Athletes’ injury histories were recorded during the competition season; and the cutoff score was set at 14, which proved to be valid by a previous study (Kiesel, Plisky, & Butler, 2007). Similar to the previous study, the athletes who had injuries during the competition season scored lower in pre-season FMS (13.9) than athletes who did not have an injury (14.7). Among individuals who scored less than 14, 68.75% of individuals sustained injuries during the competition season. These studies support the idea that movement impairment is a good indicator of potential injury.

Other injury risk factors are thought to be history of previous injury, anatomic alignment, and body composition (Cook, 2010). Among all, history of injury is considered to be the most important risk factor. If both movement impairment and previous injury are high injury risk factors, there should be a relationship between those two factors. In their study, Chorba, Bouillon, Overmyer, and Landis (2010) included seven athletes who had a history of anterior cruciate ligament reconstruction (ACLR). Interestingly, the average total score of participants including ACLR athletes are slightly higher (14.3) than the one without ACLR athletes (14.0). Therefore, they concluded that the previous injury (ACLR) did not affect the functional movement impairment. Researcher hypothesized that it is due to the emphasis of heavy rehabilitation after ACL reconstruction.

As stated above, the study showed that ACL injury history did not affect the FMS testing score. Therefore, it is the purpose of this study to examine if individuals who have CAI will demonstrate movement impairments in FMS due to its nature as a chronic condition. Some
movement patterns (RS, PU, SM, ASLR) in FMS are not directly related to ankle motion. However impairment at the ankle joint could cause compensation at other body segments. It is another purpose to see if CAI group demonstrate any movement impairment patterns which is remote to the ankle joint.
Participants

Forty four female participants (22 CAI and 22 control) were recruited from the general athletic population at a National Collegiate Athletic Association Division I university. Participants’ inclusion criteria in a study by Olmstead, Garcia, Hertel, and Shultz (2002) were used. The criteria in CAI group consisted of: (1) at least one episode of an acute lateral ankle sprain but none within the past six weeks, (2) multiple episodes of the ankle giving way within the past 12 months, (3) free of cerebral concussions, vestibular disorders, and other lower extremity injuries for three months before testing, and (4) no ear infection, upper respiratory infection, or head cold at the time of the study. The criteria in control group were following: (1) no history of injury to either ankle, (2) free of cerebral concussions, vestibular disorders, and other lower extremity injuries for three months before testing, (3) no ear infection, upper respiratory infection, or head cold at the time of the study. Participants in the control group were matched with the one in CAI group according to sex, sport, and event/position. Each participant completed a short questionnaire regarding their history and demographic information prior to the study. Data collection took place between October and November, 2011.

Testing Location, Ethics, Consent, and History

Testing location was the University of Arkansas athletic training rooms located at Barnhill arena, Bud Walton arena, and John McDonnell outdoor track field. All testing procedures were approved by the University of Arkansas Institutional Review Board. Participants in this study were informed of all approved testing procedures and risk associated
with these prior to beginning the approved testing. Additionally every participant completed an informed consent form prior to beginning of the approved testing.

Variables

The independent variable in this study was the presence of CAI. The dependent variable was the scores on FMS.

Participants Set-up

All participants wore athletic clothing and shoes during the FMS. Ankle tape or brace were worn by all participants.

Testing Protocol

Functional Movement Screening was conducted by one investigator experienced in using FMS in daily practice. All participants performed FMS while videotaped from both anterior and lateral views. The procedure, instruction, and scoring criteria of each movement were followed by the FMS instruction manual (Cook, 2010). The FMS consists of seven movements: deep squad, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push up, and rotary stability. The same instruction was given for participants in order to avoid excessive cueing. Each participant had three trials on each movement. The best score out of three trials was recorded for the overall FMS score with a maximum of 21 points. The lower number was counted toward the total score for unilateral movement patterns. General scoring criteria were following: zero for a presence of pain during the movement pattern, one for an incompletion of movement pattern, two for a completion of movement pattern with compensation, and three for completion of movement pattern without compensation.
Deep Squat

The participant stood feet shoulder width and in line with the sagittal plane. The dowel was held on top of participant’s head. The participant then squatted down as deeply as possible. The score of three was given if the participant performed a squat with the following criteria: (1) upper torso was parallel with tibia or toward vertical, (2) femur was below horizontal, (3) knees were aligned over feet, (4) Dowel did not extend past feet. If the participant demonstrated compensation, he/she was asked to perform the same motion with the heels on the board. Score of two was given if he/she was able to perform squad without compensation with the heel on the board. Score of one indicated failure of performing squad on the board.

Hurdle Step

The participant aligned their feel together with the toes touching the base of the hurdle. The length of the participant’s tibia was measured from the floor to the tibial tuberosity. The height of the hurdle was adjusted based on the length of participant’s tibia. The dowel was positioned across shoulders, just below the neck. The participant was instructed to slowly step over the hurdle, touch their heel to the floor, and return to the starting position. The stepping leg identified the side being tested. The score of three was given if participants perform hurdle step with following criteria: (1) hips, knees, and ankles remained aligned in the sagittal plane, (2) minimal to no movement was noted in the lumber spine, (3) dowel and hurdle remained parallel, and (4) foot remained dorsiflexed. Score of two was the completion of movement with compensation. Score of one was the contact between foot and hurdle and loss of balance.

In-Line Lunge

The participant was instructed to place the toe of the back foot at the end of the 2 by 6 board. Using the tibial length a mark was made on the board from the end of the subject’s toes.
The heel of the front foot was placed at the length of his/her tibial length. The dowel was held behind the back in contact with the head, thoracic spine, and sacrum. The hand that was opposite the front foot should grasp the dowel at the cervical spine and the other hand at the lumbar spine. The participant lowered the back knee to touch the board behind the heel of the front foot and returned to the original position. The front leg identified the side being tested. The score of three was given if participant performed in-line lunge with following criteria: (1) dowel contacts were remained and vertical (2) no torso movement was noted, (3) dowel and feel remained in sagittal plane, and (4) Knee touched board behind heel of front foot. Score of two was the completion of movement with compensation. Score of one was the inability to complete the lunge movement or gross loss of balance.

*Shoulder Mobility*

The participant’s hand was first measured from the distal wrist to the tip of the third digit. The participant was then asked to make a fist with each hand. The participant was instructed to assume a maximally adducted, extended and internally rotated position with one shoulder and a maximally abducted, flexed, and externally rotated position with the other. The distance between the two wrists on the back was measured. The upper/flexed shoulder identified the side being score. A score of three for the distance between wrists within one hand length, two for within one and a half hand length, and one for outside one and a half hand length. Clearing test was performed at the end of this test. The participant placed his/her hand on their opposite shoulder and attempted to point the elbow upward. A score of zero was given if the participant feels pain with the clearing test.
Active Straight Leg Raise

Participants were supine with arms in an anatomical position and head flat on the floor. The 2 by 6 board was placed under the knees. The investigator identified the midpoint between the anterior superior iliac spine (ASIS) and the knee joint line. The dowel was placed on the ground perpendicular to this position. The participant was instructed to lift the test leg with a dorsiflexed ankle and extended knee while keeping the opposite knee in contact with the board. A score of three for malleolus between midpoint on the thigh and ASIS, two for between midpoint on the thigh and the knee joint, and one for below the knee joint.

Trunk Stability Push up

The participant began in a prone position with both feet together. Hands were placed shoulder width apart with the thumbs at forehead height for males and chin height for females. With the knees fully extended and the feet dorsiflexed, the participant performed one push-up in this position with no lag in the lumber spine. By completing the push up a score of three was given. If the participant was not able to perform the push up the hands was lowered, with the thumbs aligning with the chin for males and the clavicles for females. If a push up was successful in this position a score of two was given; if not, a one was scored. At the end of this test a clearing test was given. The participant performed a press-up in the push up position. If there was in pain associated with this motion a score of zero was given for the entire test.

Rotary Stability

The participant was positioned as a quadruped with the 2 by 6 board between the knees and hands. Participant flexed the shoulder and extended the same side hip and knee. The same shoulder then extended and the knee flexed enough for the elbow and knee to touch. A score of three was given if participant performed a pattern with following criteria: spine was parallel to a
board, knee and elbow touched in line over the board. If a three was not attained, the individual performed a diagonal pattern using the opposite with the same movement pattern. A score of two was given for successful pattern without compensations. Score of one was given for incompletion of the movement pattern. The clearing test was done by a quadruped position ricking back and touching the buttocks to the heel. The hands should have remained in front of the body. The score of zero was given if participant felt pain during the clearing exam.

Data Analysis

To determine statistical significance a paired samples test was utilized to compare the total FMS scores, scores of each test between CAI and healthy group. The second paired samples test considered the injured side of the participant’s ankle for those FMS tests which required unilateral movements.
CHAPTER 4

RESULTS

Twenty six female student athletes participated in (19.5 ± 1.4 yrs; 169 ± 7.4 cm; 61.2 ± 6.4 kg). Ten additional participants were recruited for the inter-rater reliability. Inter-rater reliability of the scorer was alpha coefficient of .87. The mean total score and standard deviation (SD) of FMS in the CAI group and the control group were 15.15 ± 1.73 and 15.46 ± 1.27 respectively (maximum score of 21). There was no statistically significant difference in total scores of FMS between the CAI group and the control group (p = .61).

The mean final scores of squat, hurdle, and straight leg raise were exactly the same between the CAI group and the control group (1.62, 2.08, and 2.77). The mean final scores of lunge and trunk stability push up in the control group (2.08 ± .28, 1.92 ± .95) were less than the ones in the CAI group (2.15 ± .56, 2.00 ± .91); however, the differences were not statistically significant (p = .67, p = .85). The mean final scores of shoulder mobility and rotary stability in the control group (2.92 ± .28, 2.08 ± .28) were higher than the ones in CAI group (2.69 ± .48, 1.85 ± .38); however, there was no statistically significant differences between two groups (p = .19, p = .08). Rotary stability showed the biggest differences between CAI and control groups among seven tests; yet the difference was still not statistically significant (p = .08). Overall, there were no statistically significant differences in the mean final scores of each FMS test between control and CAI group.

Further analysis considered raw scores for the tests involving unilateral movements (rotary stability, hurdle step, and lunge). There were no statistically significant differences in mean raw scores of each FMS tests between the control and the CAI group. Rotary stability on
the right side showed the biggest differences between the CAI and the control group (p = .05); however, the difference was not statistically significant. Scores of injured side in the CAI group were compared to the matched side in control group for these unilateral movements. The mean rotary stability score of injured side in the CAI group (1.92) was lower than the matched side in the control group (2.15). The mean hurdle score of injured side in the CAI (2.19) was higher than the matched side in control group (2.12). However, these differences were not statistically significant (rotary: p = .11, hurdle: p = .61). The mean lunge score of injured side in the CAI group was exactly the same with the matched side in the control group (2.35). Even though the analysis considered the injured side, there were no statistically significant differences in mean scores of unilateral movement tests between the CAI and the control group.

The seven tests were divided into three groups: higher level movement (squat, hurdle, and lunge), mobility (active straight leg raise and shoulder mobility), and stability (trunk stability push up and rotary stability). The mean score of mobility and stability in healthy group (17.15, 8.31) were higher than ones in the CAI group (16.69, 7.69); however, the differences were not statistically significant (p = .47, p = .17). The mean score of higher level movement in the control group (14.69) was less than the one in the CAI group (14.85); and the difference was not significantly different (p = .82).
CHAPTER 5
DISCUSSION

Statistical testing examined differences of total mean scores, mean final and raw scores of each tests, injured side and the matched side for unilateral movements, and three subcategories (higher movement, stability, and mobility). Overall, this study did not find any statistically significant differences between CAI group and control group.

Though there was no statistical significance between the CAI and the control group, the FMS did supply some information. Rotary stability showed the biggest differences between CAI and control groups among seven tests (p = .08). The control group scored higher in the rotary stability test than the control group did. Since the participants were on their knees and elbows, the movement did not require the direct movements from the ankle joint, rather the rotary stability from the core musculatures. It might have indicated that participants with CAI exhibited the poorer core stability than the control group.

It should be noted that the average mean score of mobility test (2.79) was higher than that of the stability test (1.96) in total participants. Schneiders, Davidsson, Horman, and Sullivan (2011) reported that more than 90% of female participants scored either three or two in active straight leg raise test. In addition, the majority of male participants (89.1%) scored either two or one. The authors reported that similar results were observed in shoulder mobility test. Hosea and Carey (2000) investigated the epidemiology of ankle injuries in athletes. Among 4940 female and 6840 male athletes, 1052 athletes had ankle injuries. They found that females had a 25% greater risk of sustaining ankle injury than male athletes. The sex might not be the strongest risk
factor of ankle sprains; however, it appears that females may be more susceptible to sustaining ankle injuries due to high mobility and low stability compared to male athletes.

In addition, the scores of higher movement tests (squat, lunge, and hurdle) in the CAI group were either the same or even slightly higher than the scores in the control group. Since these movements need multiple body segments and functions (ROM, strength, and balance), the scores of the higher level movements, especially the hurdle step test, in the CAI group were predicted to be significantly lower than the ones in the control group. One possible explanation was the difficulty in finding completely injury-free participants for the control group at a high level of competition. The participants satisfied the all participation criteria; however, most of the participants in the control group had a history of injury. Even though the injury happened before than the criteria, it might have remained residual effect as a chronic condition. Another possibility is that the rehabilitation programs currently in place could have affected the FMS outcomes. It is important to note that all participants in the CAI group reported that they had previously completed extensive rehabilitation for their ankle instability. Similar results were observed by the study by Chorba, Bouillon, Overmyer, & Landis (2010). The study found that the average total score of the participants, including ACL reconstruction athletes, was slightly higher (14.3) than the average total score without ACLR athletes (14.0). The authors hypothesized that those who had ACL reconstruction scored higher on the FMS test due to the extended post-operative rehabilitation.
Conclusion

1. The total FMS score in participants with CAI was not significantly different from the FMS scores in the control group.

2. The mean scores of each test were not significantly different between CAI and control group.

3. Rotary stability showed the greatest movement impairment in the CAI group compared to the control group; however the difference was not statistically significant.

4. In tests with unilateral movement, the mean scores of injured side in CAI group was not significantly different from the mean scores of matched side in the healthy group.

5. The mean scores of higher movement and stability movement in CAI was not significantly different from the mean scores of healthy group.

6. Participants generally scored higher in mobility tests than stability tests.

Recommendations

The main limitation of this study was its small sample size. The study could have found statistical significance if there were more participants to examine. The main struggle to recruit participants was to be compliant with the participation criteria, such as the history of injury. There were a couple of student athletes who were initially recruited as CAI participants but needed to drop out due to the recurrent ankle sprains within 6 weeks. Since those who most frequently sprain their ankles might have shown the greater movement impairment, further participant criteria should be reviewed to make sure it does not miss out the valuable participants.
Also, it is recommended that further research involve participants at less athletic level. Participants in this study regularly engaged in weight training along with daily practice with the highest intensity for their age group. Even they exhibited the movement impairment; they might have overcome the barrier with their athletic abilities. If the future research recruits younger population without intense physical activity, it may solely see the effect of movement impairment without any external compensation.

Moreover, future research should look at the difference of CAI participants with and without the rehabilitation. All participants in CAI group in this study were engaged in ankle stability exercises along with the proper initial with their athletic trainers. Since participants in this study surprisingly scored higher scores than we expected, rehabilitation might have a positive effect to reduce the severity of CAI. It may be another interesting part to see if CAI participants with rehabilitation have score higher than those without rehabilitation.

Lastly, this study did not categorize the severity and frequency of ankle sprains in CAI. They might have been a difference between the participants who had CAI yet overcame it by rehabilitation or participants who are developing the CAI. Theoretically, participants who overcame CAI should score high in FMS. Unfortunately, the criteria that was used in this study was not as specific to categorize participants in CAI group. Therefore, it will be interesting to see how the score of CAI individuals interact with the severity and frequency of repeated ankle sprains.
REFERENCES


APPENDICES

Informed Consent

UNIVERSITY OF ARKANSAS
CONSENT TO PARTICIPATE IN RESEARCH

Title: The relationship between chronic ankle instability and functional movement impairment in division I female athletes.

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Explanation and Purpose of the Research
You are being asked to participate in a research study for Aki Tajima and Dr. Oliver. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to anonymity and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study. This study is designed to investigate the relationship between chronic ankle instability and functional movement impairment in division I female athletes.

Research Procedures
To be considered for this study, you must be deemed free of injury for the last three months, cerebral concussions and vestibular disorders, and ear infection, upper respiratory infection, or head cold. You will be required to dress in only a tee-shirt, a pair of shorts, socks, and tennis/turf shoes during testing.

You will be asked to perform seven movement patterns: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push up, and rotary stability. You will be given direct instructions on proper technique. You will have three trials on each movement. The best score out of three trials will be recorded for the overall Functional Movement Screening.

Potential Risks
Potential risks related to your participation in the study are no more than what you would encounter during the course of your regular practice or conditioning session.

Confidentiality
Confidentiality will be protected to the extent that is allowed by law. A code number will be given to all of your data information. Only the investigators will have access to the data. All data will be stored in a locked filing cabinet in the investigator’s office. The data will be erased and destroyed within fifteen years. It is anticipated that the results of this study will be published; however, no name or other identifying information will be included in any publication.

The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you should let the researcher know and she will help you. However, the University of Arkansas does not provide medical services of financial assistance for injuries that might happen because you are taking part in this research.

Participation and Benefits
Your involvement in this research study is completely voluntary, and you may discontinue your participation in the study at any time without penalty. This study will help provide insight on the effects on previous ankle sprains and functional performance in effort to design more through ankle instability rehabilitation protocols to address restoring functional movement.

Questions Regarding the Study
If you have any questions about the research study you may ask the researcher; the phone number is at the top of this form. If you have any questions about your rights as a participant in this research or the way this study has been conducted, you may contact the University of Arkansas Office of Research and Sponsored Programs at 479.575.2208 or via e-mail at irb@uark.edu. You will be given a copy of this signed and dated consent form to keep.

_____________________________________________  
Printed Name of Participant  

_____________________________________________  
Signature of Participant  Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

_____________________________________________  
Signature of Investigator  Date

FMS Score
Scoring Sheets

NAME: ________________________ AGE: ___________ HEIGHT: ___________

WEIGHT: _______________ MALE / FEMALE PHONE: ______________________

ADDRESS: __________________________________________________________

SPORT/ACTIVITY REFERENCE: _______________________________________

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Total FMS score differences

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<td>.166</td>
<td>-.593</td>
<td>.131</td>
<td>-1.389</td>
<td>12</td>
<td>.190</td>
<td></td>
</tr>
<tr>
<td>Shl.1: Shoulder mobility L raw score - Shl.2: Shoulder mobility L raw score</td>
<td>-.231</td>
<td>.599</td>
<td>.166</td>
<td>-.593</td>
<td>.131</td>
<td>-1.389</td>
<td>12</td>
<td>.190</td>
<td></td>
</tr>
<tr>
<td>Shl.1: Shoulder mobility R raw score – Shl2: Shoulder mobility R raw score</td>
<td>.000</td>
<td>.408</td>
<td>.113</td>
<td>-.247</td>
<td>.247</td>
<td>.000</td>
<td>12</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>SLR.1: Straight leg raise final score - SLR.2: Straight leg raise final score</td>
<td>.000</td>
<td>.577</td>
<td>.160</td>
<td>-.349</td>
<td>.349</td>
<td>.000</td>
<td>12</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>SLR.1: Straight leg raise L raw score - SLR.2: Straight leg raise L raw score</td>
<td>.000</td>
<td>.577</td>
<td>.160</td>
<td>-.349</td>
<td>.349</td>
<td>.000</td>
<td>12</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>SLR.1: Straight leg raise R raw score - SLR.2: Straight leg raise R raw score</td>
<td>.000</td>
<td>.408</td>
<td>.113</td>
<td>-.247</td>
<td>.247</td>
<td>.000</td>
<td>12</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>TSPU.1: Trunk stability push up final score - TSPU.2: Trunk stability push up final score</td>
<td>.077</td>
<td>1.441</td>
<td>.400</td>
<td>-.794</td>
<td>.948</td>
<td>.192</td>
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<td>.851</td>
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<tr>
<td>R.sta.1: Rotary stability final score - R.sta.2: Rotary stability final score</td>
<td>-.231</td>
<td>.439</td>
<td>.122</td>
<td>-.496</td>
<td>.034</td>
<td>-1.897</td>
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<td>.082</td>
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<tr>
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<td>-.077</td>
<td>.277</td>
<td>.077</td>
<td>-.245</td>
<td>.091</td>
<td>-1.000</td>
<td>12</td>
<td>.337</td>
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<tr>
<td>R.sta.1: Rotary stability R raw score - R.sta.2: Rotary stability R raw score</td>
<td>-.385</td>
<td>.650</td>
<td>.180</td>
<td>-.778</td>
<td>.008</td>
<td>-2.132</td>
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<td>.054</td>
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Score differences in each test