USING FUNCTIONAL PERFORMANCE TESTS FOR PREDICTING CHRONIC ANKLE INSTABILITY

by

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ABSTRACT

Functional performance deficits may be present in a population with chronic ankle instability (CAI). The purpose of this study was to determine which functional performance tests identify CAI. Seventy volunteers were divided into a CAI group of 31 and control group of 39 individuals. In a single testing session participants completed the Foot Lift Test (FLT), the Star Excursion Balance Test (SEBT), Single Leg Hop Test (SLHT), and Time in Balance Test (TIB) in a randomized order. There were no significant differences in performance between the groups. Significant correlations between the TIB and the FLT, and the SLHT and the SEBT were found. Identification of CAI group membership was statistically better than chance when either 4 FPTs (TIB, FLT, SLHT, and SEBT), 3 FPTs (TIB, FLT, and SEBT), or a single FPT (SLHT) were utilized. Clinicians may apply the SLHT as a first step in evaluation and then use the 3 other FPTs as the next step for further evaluation.

INDEX WORDS: ankle sprain; clinical tests,

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CHAPTER 1

INTRODUCTION

Lateral ankle sprains are among the most common injuries incurred during sports participation.[1,2] A previous study indicated that the ankle joint was the most commonly injured body part and that ankle sprain was the major injury of the foot-ankle region.[2] Over 23,000 ankle sprains occur every day in the U.S.[3] Based on the National Collegiate Athletic Association (NCAA) injury surveillance data, approximately 15% of all reported sports-related injuries were ankle sprains.[4] Recent epidemiological studies found that over 27,000 ankle sprains, 1,700 per year, have occurred within 16 academic years.[4] Additionally, more than 50% and 29% of all injuries in basketball and soccer, respectively, were ankle injuries.[5-7] However, only 10% of patients with ankle sprain visited an emergency room in the U.S.[5,8]

An initial ankle sprain may often result in repetitive ankle sprains. That is, individuals who have experienced an initial ankle sprain could eventually develop chronic ankle instability (CAI).[9] The primary predisposing factor of incurring an ankle sprain is a history of having had prior ankle sprains.[10] Re-spraining of the ankle is a common problem. Eighty percent of individuals with a history of ankle sprain have experienced re-spraining the ankle after the initial sprain.[1] A previous study[11] found that 40% of patients who returned to full activity after an initial ankle sprain reported persistent symptoms of CAI. Therefore, the initial ankle sprain may result in repetitive ankle sprains that can eventually lead to chronic ankle instability (CAI).[9] CAI is thought to consist of either mechanical ankle instability (MAI) or functional ankle instability (FAI) or a combination of both.[9,12] MAI denotes laxity, arthrokinematic abnormalities, and degenerative changes.[9] FAI can be caused by proprioception and neuromuscular control abnormalities.[9] These abnormal conditions may lead to the repetitive ankle sprain in individuals who have a history of ankle sprain.[1] Twenty percent of patients with acute ankle sprain have been attributed to either FAI or MAI or both conditions.[5,13]

CAI can be defined by a sensation of "giving way" at the ankle.[14,15] Furthermore, the individuals with CAI have been identified with quantifiable deficits in ankle proprioception, cutaneous sensation, nerve-conduction velocity, neuromuscular response times, postural control, and strength.[15] However, Gerber et al.[11] suggested that both history of ankle sprain and ligament laxity may not be able to predict the chronic symptoms of ankle instability.

Identifying whether or not someone has CAI, and the degree of CAI severity, can be very difficult.[16-18] Previous studies hypothesized that functional performance deficits may be present in a population with CAI.[19] It has been suggested that functional performance tests (FPTs) can be used to measure or classify the physical ability of ankle performance, but little research has been conducted on FPTs of the ankle.[14]

FPTs of the knee have been used to identify functional performance deficits.[14] The participants performed the strength and power tests on an isokinetic device, anthropometric characteristics, and functional performance tests. The participants with an anterior cruciate ligament (ACL) insufficiency who were able to return to pre-injury levels of activity performed significantly better on the FPTs than those who were unable to return to pre-injury activities.[14,20] Thus, the FPTs are the most valuable assessment of the athlete's functional capacity based on this study result.[14,20]

The balance ability of those with FAI has been measured through either instrumented or non-instrumented analysis.[21] Biomechanical force plate measures have been typically used to identify balance deficits as instrumented measures.[21,22] However, not all clinicians have access to force plates and it is also expensive and time consuming to use them. In contrast, FPTs have the advantages of being inexpensive, quick to administer, and typically accessible in clinical and field settings.[15,21,23] They may also be useful predictions of lower extremity performance, and thus able to distinguish between those with and without CAI and can be used to quantify the severity of the CAI.

Statement of problem

No clinical measuring tools such as FPTs have been established as being able to identify presence of CAI. The diagnosis of a pathological ankle condition, such as CAI, is crucial during evaluation and rehabilitation and may increase the effectiveness of rehabilitation and evaluation in the clinical setting. The problems caused by an inappropriate return-to-play decision due to lack of correct identification of chronic ankle instability also could increase the risk of recurring ankle sprain.

Unfortunately, no gold standard criterion currently exists to identify CAI group membership and severity of injury.[14] The only way researchers determine the identification of group and severity is through subjective self-reported instability on questionnaires.[14] Therefore, finding the test(s) that are strong determinants of CAI may be the first step in identifying the groups and also understanding the factors that cause patients with initial ankle sprain to develop CAI of the MAI and/or FAI form.

Ross et al[21] designed balance assessments for predicting FAI and stable ankles group membership. The authors evaluated instrumented and non-instrumented measures to determine the measure which may best predict the group membership.[21] Center-of-pressure velocity (COPV) was found to be the best measure to predict the group membership.[21] Unfortunately, most clinicians are not able to use a force plate to predict the group membership due to cost and test administration time issues. However, the validity of FPTs, and whether they can strongly predict ankle stability/instability group membership for those individuals with CAI, including MAI and FAI, is unclear.

Statement of the purpose

Investigating how to determine the status of ankle conditions may help clinicians make important decisions during evaluation and interventions, especially in the athletic population with CAI. Subjective self-report instruments such as the Cumberland Ankle Instability Tool (CAIT) have been used to classify group membership in the clinical and field setting. The CAIT questionnaire has undergone validity and reliability testing in a CAI population, unlike other instruments.[24,25] However, only applying subjective self-report questionnaires may not be the best criteria for judging if someone has CAI and how severe it is due to lack of objective measure. Adding FPTs would strengthen the delineation. Thus, the purpose of this study is to determine which FPTs best predict ankle instability or control group membership.

Significance of the study

Repeated ankle sprain after initial ankle sprain occurs at a very high rate, and it potentially develops into CAI and the loss of stability at the ankle. Also, repeated ankle sprains may lead to osteoarthritis (OA), articular lesions, degeneration, and defects, at the ankle joint.[12,26] The primary risk factor for OA at the ankle joint is repeated lateral ankle sprains.[12,26] Thus, most OA at the ankle joint is posttraumatic, and therefore preventable. There are limited successful treatment options for ankle OA.[26] Therefore, preventing repeated ankle sprains is a very important step for avoiding OA at the ankle.[12]

Non-instrumented functional performance tests have been used to detect balance deficits and determine ankle injury status.[27-30] Finding the factors that may lead to CAI is important because a predictive model can accurately provide knowledge for better treatment and rehabilitation strategies for the initial ankle sprain in select population.[12,31,32]

We examined how functional performance tests may predict ankle condition membership in the CAI or the healthy control group. This study may help clinicians determine whether the FPTs are appropriate tools for predicting the ankle condition status during the evaluation or rehabilitation phase. If the use of FPTs can significantly predict ankle stability/instability, it is likely that the effectiveness of assessment and rehabilitation may be increased.

Research Questions and Hypotheses

1. Is there a difference in functional performance test (FPT) scores of the chronic ankle instability (CAI) group and those of the control group?

H1: There is a statistically significant difference between the FPTs scores of the chronic ankle instability (CAI) group and those of the control groups.

H1a: The CAI group will have significantly less reach distance on the SEBT than the control group.

H1b: The CAI group will take significantly more time on the SLHT than the control group.

H1c: The CAI group will have significantly more errors on the FLT than the control group.

H1d: The CAI group will take significantly less time time on the TIB than the control group.

2. Are there statistically significant correlations between functional performance tests scores in the CAI group and those of the control group?

H2: There is a significant correlation between the functional performance test (FPT) scores in the chronic ankle instability (CAI) and control groups.

H2a: The SEBT will be negatively significantly correlated with the SLHT and the FLT and positively correlated with the TIB.

H2b: The SLHT will be negatively significantly correlated with the TIB and positively significantly correlated with the FLT.

H2c: The FLT will be negatively significantly correlated with the TIB.

3. Will functional performance tests (FPTs) be good predictors of chronic ankle instability (CAI) or control group membership?

H3: The functional performance tests (FPTs) will demonstrate strong prediction of group membership.

H3a: The SEBT and the SLHT will be the strongest predictors to determine CAI or control group membership.

Operational Definitions

CAI = Chronic Ankle Instability: a condition resulting from experiencing repetitive ankle sprain, leading to a combination of MAI and FAI.[9]

MAI = Mechanical Ankle Instability: an abnormal laxity of foot ankle ligaments due to structural tissue damage.[33]

FAI = Functional Ankle Instability: a subjective feeling of the ankle "giving way," and the occurrence of repetitive ankle sprains due to a lack of dynamic postural control.[34]

FLT = Foot Lift Test: a single-leg stance test to assess balance.[35]

TIB = Time in Balance Test: a functional performance test to assess the length of time participants maintain their balance.[36,37]

SEBT = Star Excursion Balance Test: a single-leg dynamic test to assess the ability of postural control.[38]

SLHT = Single Leg Hop Test: a dynamic test which requires strength, flexibility, and proprioception during single-leg jumping.[14]

CONTROL = Individuals who do not have a history of ankle sprain also known as healthy subjects.

COPER = A group of individuals who have a history of ankle sprain, but do not develop the repetitive occurrences of the symptom of giving way and who self-report higher levels of ankle function than those who complain of symptoms of CAI.[12]

Limitations

This study has some limitations. The participants were asked to provide a self-report of their ankle sprain history. However, past recall of ankle sprain injury history may be inaccurate and incomplete, as with any recall of previous medical history. Also, some participants without any history of ankle sprains (i.e., individuals in the control group) may demonstrate poor balance and poor strength on the functional performance tests (FPTs) due to their lack of physical strength. Differences in physical activity level among the participants could be a limitation as well. There are limitations in the ability of the tester to precisely time and interpret each functional test based on human error. Therefore, this study used the Windows Live Movie Maker® (Microsoft) which can measure the nearest 0.01 to minimize human error.

Furthermore, the results of the study may have limited generalizability. It may not be possible to apply the results to the general population due to the limited sample in terms of age, and physical activity level.

CHAPTER 2

REVIEW OF LITERATURE

Ankle injury is common in athletics. A history of ankle sprain is the most common cause of developing Chronic Ankle Instability (CAI). Individuals who develop CAI may be divided into those with MAI and those with FAI. However, history of ankle sprain does not always lead to CAI or a pathological condition in the ankle. Individuals with such history but with no CAI form a group known as *copers*. The exact factors that can cause and lead to these conditions are unclear. Therefore, this review is to differentiate between those with MAI, those with FAI, and copers and to discuss the risk factors contributing to these conditions.

This literature review addresses the following topics: 1) epidemiology of lateral ankle sprain 2) anatomical features, 3) pathomechanics of lateral ankle sprain, 4) pathological ankle conditions 5) functional performance tests (FPTs), 6) statistics, and 7) review of literature on methods and hypotheses.

Epidemiology

Incidence and Prevalence of Initial Sprains

Lateral ankle sprains are the most common sports-related injury.[1,2,9,39] Injury to the lateral ligaments of the ankle complex is the pathological condition resulting in the most time loss as a single sports-related injury.[39,40] The period of missing participation can vary from a couple of days to a few months depending on the severity of the ankle.[41] In basketball, over 50% of the players missed 1 week or more of participation in their sport due to ankle injury.[41] Over 23,000 lateral ankle sprains have occurred in the U.S., with approximately 10,000 lateral ankle sprains occurring every day.[3] A previous study[42] also reported that over 30% of cadets sprain an ankle during their four years at West Point, the U.S. military academy.

According to the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS), more than 27,000 ankle sprains have occurred during 16 academic years.[4] Fifteen percent of all injuries have been lateral ankle sprains based on NCAA data since 1988.[4] Also, previous studies[4,7,39] reported that the rate of ankle sprain is 15.2 per 100 participations in soccer, 3.85 per 1,000 participations in basketball, and 5.7 per 100 participations every season in high school sports.

Incidence and Prevalence of Recurrent Sprain

Of the total 563 participants, a total 414 (95.5%) have recurred ankle sprains at least twice or more times while 149 (26.5%) participants had a sprain only once.[1] Athletes who have a history of ankle sprain are more likely to resprain their ankle later.[41,43] Athletes are still exposed to the risk of ankle sprain even though they gain normal function because the primary predisposing factor of ankle sprain is a history of ankle sprain.[9,41] Individuals who have experienced repetitive ankle sprains develop functional instability.[9,44,45]

Anatomy

Bones

The tibia, fibula, and talus compose the ankle joint. The lower leg and foot are directly linked by the talus.[46] The distal fibula is known as the lateral malleoli, while the distal tibia is called the medial malleoli. These malleoli anatomically support the stabilization of the ankle joint.[46] The lateral malleoli extends further distally than the medial malleolus. This anatomical feature provides more stabilization of the lateral side ankle.[46] The joint between the talus and tibia is known as the talocrural joint, while the joint between the talus and calcaneus is known as the subtalar joint.[47]

Joints

The talocrural joint, or the ankle mortise joint, is comprised of the talus and two malleoli. The talus articulates with the tibia, and both the medial and lateral malleolus. These articulations allow motion in the sagittal plane, also known as plantar and dorsiflexion flexion in the ankle.[9]

The talus also articulates with the calcaneus in the subtalar joint which allows the motions of pronation, and supination in the ankle through multiple planes such as the frontal and horizontal planes.[9]

The inferior portion of the tibia and fibular forms the distal tibiofibular joint.[46] The distal tibiofibular joint only allows slight movement during dorsiflexion and provides stability at the ankle joint.[9]

Ligaments

The anterior talofibular (ATFL), the posterior talofibular (PTFL), the calcaneofibular (CFL) on the lateral side of the ankle, and the deltoid ligament on the medial side of the ankle are major ligaments that contribute to stability in the ankle.[9] The ATFL courses anteriorly and medially from the anterior lateral malleolus to the talus at an approximate angle of 45°.[48] The ATFL prevents the excessive anterior translation and internal rotation of the talus. The motion from dorsiflexion to plantar flexion increases tension in the ATFL.[49] The ATFL is the most common injured ligament in a lateral ankle sprain.[50] The second most common injured ligament in the ankle joint is the CFL.[51] The CFL lies on the lateral aspect of the foot and posteriorly and inferiorly courses from the lateral malleolus to the calcaneus at an angle of 133°.[48] The CFL prevents excessive supination in the talocrural and subtalar joints.[9] The tension is increased in the CFL during ankle dorsiflexion. The PTFL posteriorly courses from the lateral malleolus to the talus and restricts excessive inversion and internal rotation in the talocrural joint.[52] The PTFL is the least common injured ligament in the ankle joint.[49] The deltoid ligament, also known as the medial ligament of the talocrural, joint has two major components—the superficial and deep portion. The superficial portion of the deltoid includes the tibiocalcaneal ligament, posterior tibiotalar ligament, and tibionavicular ligament.[46] The deep portion of the deltoid is composed of the anterior tibiotalar ligament. The superficial deltoid ligament runs from the medial malleolus to the sustentaculum tali of the calcaneus, navicular tuberosity, and calcaneonavicular ligament.[46] The deep deltoid ligament courses from the inferior and posterior aspects of the medial malleolus to the medial and posteromedial aspects of the talus.[46] The deltoid ligament prevents excessive eversion in the ankle joint.[46]

Muscles

The four primary motions at the ankle joint are dorsiflexion, plantar flexion, inversion, and eversion. The primary muscles responsible for dorsiflexion include the tibialis anterior, the extensor halluces longus, and the extensor digitorum longus. The muscles that produce plantar flexion are the gastrocnemius and soleus muscles. Eversion of the ankle is produced by the peroneus longus, brevis, and terius. Everting the ankle may provide dynamic protection of the ankle from excessive inversion.[9,53,54] The tibialis posterior, flexor digitorum longus, and flexor hallicus longus are responsible for inversion of the ankle.[46] Therefore, the strength of the peroneal longus and brevis muscle may increase stability against an excessive inversion sprain at the ankle.

Pathomechanics of Lateral Ankle Sprain

The motion in the ankle, excessive plantar flexion, inversion, and internal rotation, result in lateral ankle sprains.[33] The external rotation of the lower leg and the supination of the rearfoot may give excessive stress on the lateral ligament at the ankle.[9] Increased plantar flexion at the landing is the most common mechanism for lateral ankle sprain, whereas increased dorsiflexion is the most stable position in the ankle due to anatomical structure.[9,55,56]

The ligaments at the ankle can be extremely stretched due to excessive stress when extreme inversion and plantar flexion occur during the landing from a jump on the surface. For example, this mechanism may occur when an athlete lands on an unexpected surface such as another athlete's foot. Forty five percent of the ankle injuries occur during landing and 50% of those occur when the athlete lands on another athlete's foot.[41] The ATFL is the most common ligament in the lateral ankle sprains because the ATFL has a lower maximal capacity to overcome extreme stress as compared with other ligaments in the ankle.[9,50,57] Individuals may suffer severe pain, swelling, and loss of function from the ankle sprain.[41]

Pathological Conditions

Chronic Ankle Instability

Forty to 75% of individuals with initial acute ankle sprains have a risk of recurrent sprains.[1] A previous study[44,45] by Freeman identified chronic ankle instability (CAI) as chronic or repeated incidents of lateral ankle instability (LAI) with sprains. Proprioceptive input in the ankle joint may be decreased due to deafferentation of lateral ligaments.[44] CAI results in the feeling of giving way and repetitive sprains with possible pain and swelling.[9,45] CAI may be classified into MAI, FAI, or the combination of MAI and FAI.[9]

Mechanical Instability

Pathological conditions, including laxity, arthrokinematic restrictions, synovial irritation, or degenerative changes, may cause MAI in the ankle joints.[9] The pathological alterations after ankle sprain such as hypermobility or laxity have been examined extensively at the talocrural joint.[33] The amount of damage to the lateral ligaments with the injury results in the amount of laxity in the ankle joint.[58] Laxity or hypermobility can be found at the talocrural joint even though the ligaments are fully treated after an acute ankle sprain.[58] Increased joint laxity may cause recurrent ankle sprains in the common injury mechanism. A previous study[58] found that significantly more laxity at the talocrural joint had been measured in individuals with CAI through an anterior drawer and a talar tilt test while only 42% of CAI participants showed a positive anterior drawer test in another study.[43] Mechanical instability at the talocrural joint may be a common symptom, but it may not necessarily be presented in all individuals with CAI.[43]

Arthrokinematic change after the initial ankle sprain may also be the cause of recurrent ankle sprains in individuals with CAI.[59] Excessive anterior and inferior translation of distal fibula may occurr due to less tightness of the ATFL in a resting position.[59] Pathological limited arthrokinematics may decrease the dorsiflexion range of motion (ROM) in the ankle joint.[9] Decreased dorsiflexion ROM may obstruct the ankle joint from reaching the closed-pack position.[9] Therefore, the athletic who suffers limited dorsiflexion may be exposed to a high risk of ankle injury mechanism due to allowing easier inversion and internal rotation. Additionally, MAI may lead to synovial inflammation and degenerative change in the ankle joint.[9]

Functional Instability

Functional ankle instability (FAI) can be described as a functional disability of the ankle.[45] Patients with FAI reported that a residual symptom of ankle sprains is the feeling of their foot “giving way.”[45] Twenty to 50% of individuals with initial ankle sprain reported residual symptoms.[45,60,61] On the other hand, one previous study reports that FAI may be a participative complaint of instability in the absence of mechanical disruption.[62] FAI may be linked to deficits in proprioception and neuromuscular control.[9] The neuromuscular system may play a role in dynamic support of the ankle.[9] An individual’s position sensor in the ankle joint becomes hampered when the ankle joint is injured. A disabled position sensor in the ankle joint may decrease its ability of proper stabilization which may prevent injury.[63] Decreasing proprioception function may decrease the ability to stabilize the joint which limits that joint’s Range of Motion (ROM) excess beyond anatomical limitation. Loss in proprioception function may more likely be the cause of reoccurring ankle sprains.[45] A study conducted by Freeman et al[45] found that the damaged mechanoreceptor following ankle sprains may result in decreased proprioceptive input in the ankle joint. Additionally, Lentell et al[64] revealed that the damaged type II mechanoreceptor following ankle sprains may significantly decrease passive motion in the ankle joint.

Individuals who suffer from acute ankle sprain and CAI present impairments of postural control in the ankle joint.[9] Proper postural control in the ankle joint may be derived from an “ankle strategy” which maintains the center of gravity.[9] Additionally, research[65] has found that abnormal postural control ability may increase the risk of ankle sprains, and greater deficits in postural control have been found in individuals suffering from acute ankle injury than in health individuals without a history of ankle injury. Also, individuals with CAI presented a significantly lower outcome in the Star Excursion Balance Test (SEBT), one of the measuring tools for dynamic postural control, than the SEBT outcome for their uninvolved ankle.[66]

Copers

Chronic ankle instability is a common injury during sports activity.[1,2,67] Chronic ankle instability may cause not only acute signs and symptoms but also the long-term effects after initial ankle sprains.[12,26] However, some individuals known as c*opers* do not have any common consequence of lateral ankle sprains or pathological conditions such as recurrent ankle sprains and giving way episodes after initial ankle sprains. [12,68] An unknown mechanism in copers may allow them to avoid pathological conditions related to lateral ankle trauma.[12,68,69] A previous study[32] only found that copers present higher frontal plane direction of the Dynamic Postural Stability Index (DPSI) than individuals with CAI. Higher frontal plane DPSI may be one of the coping mechanisms that prevent residual symptoms and CAI condition.[32] Wikstrom et al's[70] study also found that perception-based outcomes known as a self-report questionnaire of ankle function has the capability of distinguishing between copers and CAI. Brown et al[12] also reported that greater ankle frontal plane movement was presented in individuals with FAI. However, there was no visual difference in kinematic patterns between individuals with FAI and copers even though participants reported differences through perception-based outcomes.[12] Therefore, future research should be conducted to identify the different mechanism that results in copers and to find the clinical measuring tools which are able to discriminate between individuals with CAI and copers.

Consequences of Chronic Ankle Stability

The enduring signs and symptoms related with repetitive ankle sprains may lead to very different pathological clinical conditions. For example, recurrent sprains have been linked to the long-term consequences such as osteoarthritis (OA) and articular degeneration in the ankle joint.[71,72] Six percent of ankle OA patients with history of ankle sprains have been prevented from returning to their activities and 13 – 15% of them abide in occupational disability from a minimum 9 months to a maximum 6.5 years.[73,74] Previous studies[18,26] found that repetitive lateral ankle sprains may be the most common cause of ankle OA and increased risk of articular lesions, degeneration, and defects, even though the relationship with ankle OA is not clear. Therefore, preventing CAI may prevent the further chronic long-term effects such as OA.[12,26] The rehabilitation plan, the application of the devices such as bracing, and proper neuromuscular control training could be applied if the pathological movement mechanism develops the long-term effect in the ankle joint.[12]

Quantifying Ankle Instability

The ankle conditions, FAI, MAI, and Copers, may be classified through the use of questionnaires. However, there is no gold standard tool which researchers and clinicians may apply to discriminate the various ankle conditions.

The Cumberland Ankle Instability Tool (CAIT) is a commonly used questionnaire.[35] The CAIT includes 9 questions to determine severity of ankle instability. A possible maximum score is 30, with a score greater than 28 indicating a highly stable ankle. A previous study[24] by Hiller et al. found that the score of 27.5 shows the maximum of Youden's index (68.1 = sensitivity (%) + specificity (%) – 100). The sensitivity of CAIT is 82.9% and specificity is 74.7% with a positive likelihood ratio of 3.27 and a negative likelihood ratio of 0.23.[24] Thus, Hiller et al.[24] suggested that clinicians and researchers may apply the score of 28 as an indicator of ankle instability. A score less than 28 but greater than or equal to 24 indicates moderately unstable ankle.[35] This measure has shown significant high test-retest reliability (0.96).[24] The CAIT has also shown significant correlation with the Lower Extremity Functional Scale and the Visual Scale.[24]

Functional Performance Test

Star Excursion Balance Test

The star excursion balance test (SEBT) is a clinical measuring tool used to measure dynamic postural control. The SEBT has been applied to detect functional performance deficits.[75] The SEBT consists of 8 directions in which the participants attempt to reach as far as they can with one leg while standing on the opposite leg. The task requires proper postural control ability, strength, flexibility, and motion of the stance limb.[76] The ability of the participants to reach further during single-leg stance may represent improved functional performance.[75] Reach distance is normalized to leg length. Hubbard et al.[77] reported that the anteromedial and posteromedial reach directions identified persons with chronic ankle instability. Lower extremity injury in high school basketball players was predicted by the sum of three reach directions (anterior, posteromedial, and posterolatreal).[38,78] Most researchers have simplified the SEBT to the posteromedial, posterolatreal, and anterior reach directions.[78] Thus, Plisky et al[38,78] suggest using only the anterior, posteromedial, and posterolatreal directions in the SEBT as a clinical measuring tool due shorter testing time.

Foot Lift Test

The Foot Lift Test (FLT) is a clinical static balance test similar to the Balance Error Scoring System (BESS) except that the FLT only uses the single-leg stance. The FLT may detect differences between individuals with and without FAI.[35] Participants without history of ankle sprains have presented better scores on the FLT than participants with FAI.[35] Participants stand barefoot in a single-leg stance, with hands on hip, and looking straight ahead. Participants maintain their balance without opening their eyes and using their other extremities. The number of times the foot, or any part of the foot, is lifted is counted during the 30 seconds.[35] A “part of the foot lift" can be defined as "any part of the foot such as metatarsal, toes, or heel lifts up from the surface.[35] Also, 1 error is counted if the un-testing foot touches the surface.[35] A participant presenting fewer foot lifts could be considered as having better static balance function through the FLT. Furthermore, a meta-analysis study found that the FLT demonstrated very strong outcomes which were strongly associated with presence of FAI and was easily employed in the clinical setting.

Time in Balance Test

The Time in Balance Test (TIB) is a static balance test. The TIB also uses the single-leg stance and measures how long a participant can maintain the position before moving the test foot or touching the floor with the contralateral foot. Participants maintain their balance in the single-leg stance without shoes or socks and with eyes closed for 60 seconds. However, the test may be stopped before 60 seconds if the participant loses balance. The loss of balance may be defined as 1) moving the testing foot or 2) touching the ground with the non-testing foot.[22,36] Participants with a history of ankle sprain demonstrated shorter stance time.[36] Also, the stance time on the injured ankle was significantly shorter than on the uninjured ankle and in a healthy group.[36] The TIB can also be easily applied to the clinical setting. Ross et al.[21] and Chrintz et al.[36] found that the TIB outperformed not only other clinical balance tests but also force plate outcome measures in identifying balance deficits.

Single-leg Hop Test

The Single-Leg Hop Test (SLHT) is a more functional test compared to the SEBT, FLT, and TIB because it requires performance of tasks similar to sport. Participants hop laterally over a 30 cm distance and back for a total of 10 repetitions in the single-leg stance, barefoot, as quickly as they possibly can. The time is recorded to determine how fast participants complete the task. The SLHT had a significantly high ability to predict the participant's self-report ankle function questionnaire score.[79] Furthermore, Docherty et al[19] found that SLHT forced the participants to move laterally, producing stress on the lateral ligaments of the ankle. A positive correlation was found between the self-reported Functional Ankle Instability Index and the SLHT.[19] Also, the SLHT has the advantage of being easily employed in the clinical setting.

Review of Other Literature Related to Statistics

A previous study[21] used linear regression for analysis because the regression analysis method can estimate the conditional expectation of the dependent variable (Group Conditions) given the independent variables (FPTs). Regression analysis method is commonly applied to know how the typical value of the dependent variable (Group membership either CAI and control group) changes when one of the independent variables (FPTs) is varied.

CHAPTER 3

METHODS

Overview

Seventy participants were recruited for this research, 31 participants with chronic ankle instability (CAI), and 39 participants without a history of repeated ankle sprains (Control). Participants were asked to come to the University of Georgia Biomechanics Laboratory for 1 session of data collection. Participants underwent an ankle joint physical assessment and, functional performance tests, and answered questions about their perceived ankle function, for total participation time of approximately 1 hour.

Subjects

Participants were recruited from the physical activity classes and club teams of the University of Georgia based on their physical activity level. The researcher provided an orientation to participants regarding the test procedures and consent form that is approved by the Committee for the Protection of the Rights of Human Subjects at the University of Georgia.

To participate in the study, participants had to be between 18 and 25 years of age and had to participate in physical activities, such as running, walking, lifting weights, or playing sports, for at least 90 min per week. In addition, the participants had to meet one of the following criteria: 1) no history of sprained ankle; or 2) a history of ankle sprain requiring at least 3 days of crutches, brace, or limping, and having experienced rolling, re-spraining, or a feeling "giving away" at least twice in the past 12 months. Exclusion criteria for all participants was a history of any of the following: 1) surgery and fracture in lower extremity; 2) current signs and symptoms of acute ankle sprains such as swelling, discoloration, heat, and pain; 3) pregnancy; or 4) diagnosis of a vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder, or other nerve or connective tissue issues.

Instrumentation

MotionMonitor™ software version 8.35 (Innovative Sports Technologies Inc., Chicago, IL) and DCR-TRV280 Digital Video Camera Recorder (Sony®, San Diego, CA) were used to collect the video data during the Time in Balance Test (TIB), Foot Lift Test (FLT), and Single-Leg Hop Test (SLHT). Athletic tape was used to mark the floor to show where the participant should place the test foot in different locations during the Star Excursion Balance Test (SEBT). Also, Baseline® Hi-Res™ 12 inch goniometers (Fabrication Enterprises, Inc., White Plains, NY) were used to place the athletic tape at the appropriate locations for the SEBT.

Procedure

Participants were asked to wear comfortable athletic clothing and no shoes for the test session. Participants received an orientation to the testing procedures and read a consent form which was approved by the committee for the protection of the rights of human participants at the University of Georgia. Participants who met the inclusion criteria signed the consent form and completed the Injury History and Activity and Cumberland Ankle Instability (CAIT) questionnaires (Appendix A). [24,25,80] The participants' height, mass, age, gender, and leg lengths were recorded. The dominant side was the limb the participant used to complete 2 out of the 3 following tasks: 1) kick a ball, 2) his or her first step on the stairs, and 3) step forward to maintain balance following a gentle push from behind.[81] A single researcher consistently measured active ankle Range of Motion (ROM) to maintain high reliability. The reliability was established as good (ICC: 0.8 or higher for each direction). A standard goniometer was used to measure the ROM. Participants sat on the edge of the table to measure the ROM through plantar flexion, and dorsiflexion with knee flexion. Also, inversion, eversion, and dorsiflexion with knee extension were measured in prone position on the table. A single researcher performed an ankle evaluation for joint laxity utilizing the anterior drawer and talar tilt tests which apply an anterior load and a supination torque to the foot while participants sit on the edge of table.[82,83] Participants completed the functional performance tests including the SEBT, FLT, TIB, and Single-Leg Hop Test (SLHT), in a random order determined by the participant who drew a card with a number that represented the order.

Participants performed the TIB on a stable surface in a single-leg stance according to published directions.[36] Participants were instructed to keep their eyes closed, and their hands on their hips (at the iliac crests), and remain as motionless as possible for up to 1 minute. Participants were videotaped. A single rater viewed the video at a later date and used a stopwatch to time how long a participant was able to remain in the testing position. The rater stopped timing when the subject lost balance or made an error such as moving the testing foot or touching the floor with the un-tested foot. Three trials were collected on each foot. The maximum length of the test was 1 minute in each trial. We used the mean of trials as indicated by the longest TIB, the same as in the previous study.[36]

For Foot Lift, participants were in the same position as the TIB. Participants stood for 30 seconds and were videotaped. After testing, the single rater watched the video and scored the number of foot lifts during the 30.[21,35] Foot lift” can be described as lifting any part of the foot, such as toes or heel, from the surface.[35] Also, if the un-tested foot touched the floor, this was considered as an error.

Prior to performing the Star Excursion Balance Test (SEBT), leg length was assessed in a supine position from the medial malleolus to anterior superior iliac spine (ASIS) of each limb to normalize with distance.[84] The SEBT was performed in a single-leg stance. Participants stood barefoot at the center of a grid where 2 lines were extended at 45° and marked by the athletic tape. The center of the foot (highest point of arch) was placed at the center of a grid. Participants were instructed to reach with the un-tested leg to touch as far as they could along the line while in a single-leg stance with the testing leg. The participants were instructed to keep the foot in the same position throughout the duration of data collection. The researcher monitored the foot position and marked the point touched along the line from behind the participant throughout the data collection. The testing foot was not moved from the center of the grid during the 3 trials, but if it was moved, the researcher repositioned the testing foot. Hertel et al[85] found that Posterior Medial (PM) reach direction was highly representative of all 8 directions. Therefore, PM was used for this study, as it is identified as the strongest indicator of CAI.[38,78] Participants had 3 practice trials in the PM directions before the data collection. For data collection, participants performed the 3 trials on each foot. The mean distance from the 3 trials was used.

The participants also performed the Single-Leg Hop Test (SLHT). Participants were instructed to complete a task of lateral hopping (30 cm distance between start point and end point) and come back to the point where they started for 10 repetitions.[19] The test was videotaped. After testing, a single rater watched the video and recorded the finish time to the nearest 0.01 second. Participants completed two test trials with no practice trial, based on previously published instructions.[19] A 1-minute rest break was offered between the first and second trials. The best completed time was used for data analysis in the previous study.[19] However, in this study the mean of two trials for the SLHT was used to analyze data because the mean outcomes may be a better explanation for the typical performance in the general population.

The FPTs were performed barefoot and order was randomly assigned to minimize potential for fatigue. At least a 30-second rest break between trials and a 1-minute rest break between tests were provided to avoid fatigue.[19,35,36]

Prior to data scoring, intra-rater reliability was assessed for each FPT. Two trials for the TIB, FLT, and SLHT from 20 randomly selected pilot participants were used. The rater scored them repeatedly over 3 days. The reliability program in SPSS (SPSS, Inc., Chicago, IL) was used to calculate the reliability of a score which is the mean of two trials administrated on one day.[86] The reliability was tested for the researcher scoring the SLHT, FLT, and TIB was also performed based on collected data.

Data Collection and Reduction

The reliability was tested before the researcher scored the SLHT, FLT, and TIB. The reliability test for the SEBT was performed based on collected data, and represented consistency of participant performance. All FPTs were videotaped during data collection to score each test. The video was played through the Windows Live Movie Maker® (Microsoft) to measure to the nearest 0.01second. After all testing, a single rater reviewed the video and scored for the SLHT, FLT, and TIB. The means of time in the TIB, number of errors in the FLT, and distance in the SEBT were collected. Also, the shortest completed time was used for the SLHT. The data from the 3 trials were collected for analysis. The mean from 3 trials was used for the TIB, FLT, and SEBT.[35]

Statistical Analysis

Means and standard deviations were calculated as exploratory descriptive data of the subjects' demographics and performance on each clinical test. A series of independent sample t-tests were used to determine group differences on FPT scores for each test. An alpha level of $p \leq 0.05$ was set a priori to indicate statistical significance. Effect sizes (Cohen's *d*) and Power (1-ß err prob) for each test were also calculated. Pearson product-moment correlation coefficients (Pearson's r values) were calculated to determine if scores on functional performance tests were related. Linear regression was used to determine which of the FPTs best predicted group membership (CAI and Control). R (multiple correlation coefficients) values indicated the strength of the association between the dependent (ankle condition) variable and the independent variable (FPTs). The group membership coded score was 0 = CAI and 1 = Control. Predicted scores were rounded to 0 when the predicted values was less than .5 while predicted score of .5 or higher was rounded to 1. Number and percentage of correctly classified group memberships were calculated, and Z test was calculated to determine if the classification was better than chance. Chance was defined as 50%, the value indicative of no ability to predict. The hypothesis utilized was "better than chance," or better than 50%, because prediction could not be "worse" or less than chance. The statistical Package for the Social Sciences 20.0 (SPSS, Inc., Chicago, IL) was used to perform all statistical analyses.

CHAPTER 4

ASSESSING CLINICAL EFFECTIVENESS OF FUNCTIONAL PERFORMANCE TESTS FOR PREDICTING CHRONIC ANKLE INSTABILITY AND STABLE ANKLE[1]

[1] Ko, J.P., Rosen, A.B., Simpson, K.J., Baumgartner, T.A. and Brown, C.N. To be submitted to *Journal of Athletic Training*

Abstract

Context: Functional performance deficits may be present in a population with chronic ankle instability (CAI), but it is unclear which tests are most effective at determining if an individual has CAI. **Objective:** To determine which functional performance tests identify group membership based on the self-report ankle function. **Design:** Cross-sectional. **Setting:** Biomechanics Laboratory. **Patients or Other Participants:** Seventy volunteers were divided into a CAI group of 31 (11 males, 20 females; age= 20.58 ± 1.34 yrs; height= 167.64 ± 9.12 cm; mass= 68.65 ± 11.53 kg) and control group of 39 (19 males, 20 females; age= 19.92 ± 1.18 yrs; height= 169.29 ± 10.62 cm; mass= 68.73 ± 13.09 kg). **Interventions:** In a single testing session participants completed the Foot Lift Test (FLT), the Star Excursion Balance Test (SEBT) in the posteromedial direction, the Single Leg Hop Test (SLHT), and the Time in Balance Test (TIB) in a randomized order. A linear regression model was applied to determine measures that predicted ankle group membership (CAI and Control). **Main Outcome Measures:** The mean SEBT reach distance of 3 trials was normalized to % leg length. Both the SLHT and TIB were reported as time in seconds, and the mean of 2 trials and 3 trials, respectively, was calculated. **Results:** Combining four FPTs (TIB, FLT, SLHT, and SEBT) and combining three FPTs (TIB, FLT, and SEBT), and single SLHT resulted in correct classification (60-64%) of participants into groups which is significantly better than chance. **Conclusions:** Use of a single or combination of FPTs results in correct classification participants into CAI or control groups, which is better than chance. FPTs may have some limited usefulness in determining ankle function. **Word Count**: 275

Introduction

Lateral ankle sprains are among the most common injuries incurred during sports participation.[1,2] The National Collegiate Athletic Association (NCAA) injury surveillance data show that approximately 15% of all reported sports-related injuries are ankle sprains.[4] The ankle sprain incidence rate of 2.15 per 1000 person-year in the general population in the United States has been reported; however, in the intercollegiate athletic population the rate reported was 58.4 per 1000 person-year.[87,88] Initial ankle sprain may result in repetitive ankle sprains and drive individuals with history of ankle sprain into Chronic Ankle Instability (CAI).[9]

CAI can be defined as sensation of "giving way" at the ankle.[14,15] The primary predisposing factor of ankle sprain is history of ankle sprain.[10] Approximately 80% of individuals with a history of ankle sprain have experienced re-spraining the ankle after the initial sprain.[1] Forty percent of patients in the athletic population who returned to full activity after an initial ankle sprain reported persistent symptoms of CAI.[11] The primary risk factor for osteoarthritis (OA) at the ankle joint is repeated lateral ankle sprains.[26] In detail, OA may lead to articular lesions, degeneration, and defects, at the ankle joint..[12,26] Preventing repeated ankle sprains is a very important step for avoiding OA at the ankle joint.[12] Although predicting and rehabilitation in the clinical setting, it can be very difficult to predict and identify CAI and the degree of severity. [16-18]

Biomechanical instrumented tools such as center-of pressure velocity (COPV), medial lateral stability index (MLSI), anterior posterior stability index (APSI), and dynamic postural stability index (DPSI) have been applied to determine balance deficits to discriminate between the group membership.[89,90] However, most clinicians do not have access to costly and time consuming biomechanical instruments such as a force plate to predict group membership. Therefore, finding the non-instrumented test(s), such as Functional Performance Tests (FPTs), that are strong determinants of CAI may be useful. These FPTs have the advantages of being inexpensive, quick to administer, and typically accessible in clinical and field settings.[15,21,23]

FPTs of the knee have been measured to identify functional performance deficits, but little research has been conducted on FPTs of the ankle. [14,20] In one study, the participants with an Anterior Cruciate Ligament (ACL) insufficiency who were able to return to pre-injury levels of activity performed significantly better on the FPTs than those who were unable to return to pre-injury activities.[20] Thus, FPTs the most valuable assessment of the athlete's functional capacity based on this study result.[14,20] Docherty et al[19] found that functional performance deficits were present on the side hop and the figure-of-8 hop test in patients with CAI. Therefore, Functional Performance Tests (FPTs) may be able to measure or classify physical ability of ankle joint performance in the same way they are used for knee performance.[14] However, only limited information is available regarding the ability to predict CAI group membership using FPTs.

Therefore, the purpose of this study is to determine which functional performance tests identify group membership based on the self-report ankle function. This study may help clinicians determine whether FPTs are appropriate tools for predicting the ankle instability status during the evaluation or rehabilitation phase after ankle injury. If the use of FPTs can significantly predict membership in CAI or control group, it is likely that the effectiveness of assessment and rehabilitation may be increased.

It was hypothesized that the FPTs would demonstrate strong prediction of CAI or control group membership. Specifically, the results of the single-leg-hop test (SLHT) and Star excursion balance test (SEBT) would be the strongest predictors of group membership.

<u>Methods</u>

Participants

Participants were recruited from physical activity classes and club teams of the University of Georgia. The researcher provided an orientation to participants regarding the test procedures and consent form approved by the Committee for the Protection of the Rights of Human Subjects at the University of Georgia. Seventy participants were recruited for this research: 31 with chronic ankle instability (CAI) and 39 without a history of ankle sprains (Control). Demographics are reported in Table 1. All participants were between 18 and 25 years of age and participated in physical activity, such as running, walking, lifting weights, or playing sports, for at least 90 min per week. The CAI group reported ≤ 24 on the Cumberland Ankle Instability Tool (CAIT) questionnaire and a history of ankle sprain(s). Participants who reported ≥ 28 on the CAIT questionnaire and no history of ankle sprain(s) were placed into the Control group.[24,35]

Procedures

Following informed consent, participants who met the inclusion criteria completed the Cumberland Ankle Instability Tool (CAIT).[24] A single researcher measured ankle Range of Motion (ROM). The rater’s reliability was established as good. A standard goniometer was used to measure ROM. Participants sat on the edge of the table to measure the ROM through plantar flexion, and dorsiflexion with knee flexion. Also, inversion, eversion, and dorsiflexion with knee extension were measured in prone position on the table.

Participants completed the functional performance tests (FPTs), including the Time in Balance Test[91-93] (TIB), Foot Lift Test[35] (FLT), and Single-Leg Hop Test[19,79] (SLHT), in a random order determined by each participant drawing a card with a number. All FPTs were videotaped with a DCR-TRV280 Digital Video Camera Recorder (Sony®, San Diego, CA).

Participants performed the TIB on a stable surface in a single-leg stance according to published directions.[36] Participants were instructed to keep their eyes closed and their hands on their hips (at the iliac crests), and remain as motionless as possible for 1 minute. A single rater viewed the video at a later date and used a stopwatch to time how long a participant was able to remain in the testing position. The rater stopped timing when the subject lost balance or made an error such as moving the testing foot or touching the floor with the un-tested foot. Three trials were collected on each foot. The maximum length of the test was one minute in each trial. The mean of trial was used as the TIB score rather than.[36]

For the Foot Lift Test, participants were in the same position as required for the TIB. Participants stood for 30 seconds and were videotaped. After testing, the single rater watched the video and scored the number of foot lifts, or part of foot lifts, during the 30 seconds.[21,35] A “part of foot lift” can be described as lifting any part of the foot such as toes or heel, from the surface.[35] Also, if the un-tested foot touched the floor, this was considered an error.

Prior to performing the Star Excursion Balance Test (SEBT), leg length was assessed in a supine position from the medial malleolus to the anterior superior iliac spine (ASIS) of each limb.[84] The SEBT was performed in a single-leg stance. Participants stood barefoot at the center of a grid where two lines were extended at 45° and marked by athletic tape. The center of the foot (highest point of arch) was placed at the center of a grid. Participants were instructed to reach with the un-tested leg to touch as far as they could along the line while maintaining a single-leg stance with the testing leg. Hertel et al[85] found that Posterior Medial (PM) reach direction was highly representative of all 8 directions. Therefore, PM was used for this study, as it is identified as the strongest indicator of CAI.[38,78] Participants had 3 practice trials of the PM directions before the data collection. For data collection, participants performed the 3 trials on each foot. The mean distance from the 3 trials was used as the score of a participant.

The participants also performed the Single-Leg Hop Test (SLHT). Participants were instructed to complete a task of lateral hopping (30 cm distance between start point and end point) and then come back to the point where they started for 10 repetitions as fast as they could while meeting the required distance.[19] After testing, a single rater watched the video and recorded the finish time to the nearest 0.01 second. Participants completed 2 trials without a practice trial. A 1-minute rest break between tests was provided to avoid fatigue.[19,35,36]

Data Analysis

Rater reliability for the single rater scoring the SLHT, FLT, and TIB was established to ensure consistent scoring across and between participants. Also, the reliability of the performer in the SEBT was completed based on collected data. Rater reliability was established using Intra Class Correlation Coefficients ($ICC_{(2,1)}$) and Standard Error of the Measure [SEM]).[86] All videos were played through Windows Live Movie Maker® (Microsoft) to measure time to the nearest 0.01second.

Means and standard deviations were calculated as exploratory descriptive data of subjects' demographics and performance on each FPT. Means were calculated across trials for TIB, FLT, SLHT and SEBT. Linear regression was used to determine which of the FPTs best predicted group membership (CAI and Control). R (multiple correlation coefficients) values indicated the strength of the association between the dependent (ankle condition) variable and the independent variable (FPTs). The group membership coded score was 0 = CAI and 1 = Control. Predicted scores were rounded to 0 when the predicted values was less than .5 while a predicted score of .5

or higher was rounded to 1. Number and percentage of correctly classified group memberships were calculated, and a Z test was calculated to determine if the classification was better than chance. Chance was defined as 50%, the value indicative of no prediction. The main hypothesis was 50% and the alternated hypothesis was "better than chance," or better than 50%, because prediction could not be "worse" or less than chance. An alpha level of $p \leq 0.05$ was set *a* priori to indicate statistical significance. The Statistical Package for the Social Sciences 20.0 (SPSS, Inc., Chicago, IL) was used to perform all statistical analyses.

Results

Mean and standard deviations for demographic and FPTs are reported in Tables 1 and 2. The reliability for intra-rater in the TIB, FLT, and SLHT and scores in the SEBT is reported in Table 3.

Table 1. Mean (±Standard Deviation) of Subjects' Demographics

Group	Age (yr)	Height (cm)	Mass (kg)	Test Limb
CAI (N=31)	20.58 (±1.34)	167.64 (±9.12)	68.65 (±11.53)	Right = 18
Female 20	20.50 (±1.61)	162.41 (±5.11)	63.52 (±9.12)	Left = 13
Male 11	20.73 (±0.65)	177.15 (±6.76)	78.00 (±9.59)	
Control (N=39)	19.92 (±1.18)	169.29 (±10.62)	68.73 (±13.09)	Right = 27
Female 20	19.75 (±0.97)	161.66 (±5.45)	60.61 (±9.30)	Left = 12
Male 19	20.11 (±1.37)	177.32 (±8.59)	77.27 (±10.96)	

Note. CAI = Chronic Ankle Instability

Table 2. Mean (Standard Deviation) of Functional Performance Tests

Group	Foot Lift (# of errors)	Time in Balance (sec)	Single Leg Hop (sec)	Star Excursion Balance (cm)
CAI (N=31)	9.38 (±7.76)	41.70 (±16.23)	17.58 (±5.54)	88.36 (± 1.69)
Control (N=39)	6.96 (±5.34)	43.67 (±13.99)	15.18 (±5.09)	91.66 (± 10.20)
P	0.127	0.587	0.064	0.168

Chronic Ankle Instability (CAI)

Table 3. Estimates of Reliability and Standard Error of Measurement (SEM)

Measure	Intra-class Correlation Coefficient ($ICC_{(2,1)}$)	SEM
Time in Balance (TIB)	0.96	4.4 (sec)
Foot Lift Test (FLT)	0.97	1.3 (# of error)
Single Leg Hop Test (SLHT)	1.00	0.06 (sec)
Star Excursion Balance Test (SEBT)	0.71 (Left) 0.79 (Right)	4.6 (cm) 4.6 (cm)

Intra-rater reliability in TIB, FLT, and SLHT
Performer's reliability in SEBT

Identification of CAI group membership was statistically better than chance when either 4 FPTs (TIB, FLT, SLHT, and SEBT), 3 FPTs (TIB, FLT, and SEBT), or a single FPT (SLHT) were utilized, indicated by a significant value of the Z-test on a proportion (Z=1.645). An approximately 60-64% of participants were correctly assigned to groups, while chance assignment would be 50%. No statistically significant relationships were found for other combinations of FPTs or single FPTs. The multiple correlation coefficients (R value) for the regression equation, and number and percentage of correctly identified group memberships are reported in Table 4.

Table 4. Statistical Results of Multiple Linear Regression.

Test(s)	R	# of correctly classified participants (n = 70)	% of correctly classified participants	Z
TIB/FLT/SLHT/SEBT	.298	45	64.29	**2.343***
TIB/FLT/SEBT	.241	45	64.29	**2.343***
TIB/FLT/SLHT	.286	43	61.43	1.841
TIB/SLHT/SEBT	.243	43	61.43	1.841
FLT/SLHT/SEBT	.292	43	61.43	1.841
TIB/SLHT	.223	43	61.43	1.841
FLT/SEBT	.240	43	61.43	1.841
FLT/SLHT	.279	42	60.00	1.673
SLHT/SEBT	.243	42	60.00	1.673
SLHT	.223	42	60.00	**1.645***
TIB/SEBT	.176	41	58.57	1.506
SEBT	.167	41	58.57	1.506
TIB/FLT	.185	40	57.14	1.171
FLT	.184	39	55.71	1.003
TIB	.066	38	54.29	0.669

*Z= 1.645 significant at alpha = 0.05; one tailed test

Discussion

Our most important finding was that combining all 4 FPTs (TIB, FLT, SLHT, and SEBT) or 3 FPTs (TIB, FLT, and SEBT) showed the highest % of correct classification value for CAI versus control group membership, though the R and % of correct classification was still relatively low. Also, the SLHT showed the highest predictive value as a single FPT, but the R and % of correct classification was still low overall. These results support most of our hypotheses. What was not supported was that SEBT was not a strong test to predict the group membership. There appears to be some limited clinical usefulness for utilizing FPTs to determine if CAI is present or not in a group of recreational athletes.

Although Demeritt et al[28] reported that there is no relationship between the FPTs and CAI, previous researchers[15,19] have established that functional performance deficits are displayed in a CAI population. However, there is still no validated or gold standard clinical measuring tool.

Our results support Demeritt et al[28] in that we were unable to find a highly useful FPT among the 4 we studied. The low correlation coefficient (R) values between the FPTs and group membership in this study may be due to the nature of the functional tests. In the literature, researchers have reported that patients with CAI showed balance deficits during functional performance tests which placed rotary or multiplnar demands on the ankle.[29] Docherty et al[19] found functional performance deficits in patients with functional ankle instability (FAI) while they performed the figure-8 hop and side-hop tests which required frontal-plane movement. However, 3 FPTs (TIB, FLT and SEBT) in this study did not require frontal-plane movement, but were instead stationary, or only semi-dynamic. The SLHT was the only test that included a frontal-plane functional performance activity in this study. It was also the only test that rose to statistical significance by itself. Therefore, the SLHT may be the most useful test among the 4 we utilized to predict ankle instability, though its usefulness is still questionable.

Our findings also indicate that the posteromedial reach of the SEBT was not a strong clinical measuring tool to predict ankle instability. Though the SEBT has been validated and shown to be a reliable clinical measuring tool to assess dynamic postural control in a CAI population,[17,78,94,95] our finding may emphasize that the posteromedial reach of the SEBT may not be demanding enough to distinguish between groups. While the SLHT was able to distinguish to an extent between CAI and controls, the SEBT was not, and perhaps should be considered as a "low-intense," "semi-functional," or "semi-dynamic" functional test instead of a "dynamic postural stability test." Participants may have experienced lower functional demand with the SEBT than with some other FPTs. Patients with a severe pathological condition could be detected through "low-intense" or "semi-dynamic" FPTs such as the SEBT, but it is questionable whether a mild case of CAI condition could be detected in patients.

While combining 3 and even a single FPT was better than chance in predicting group membership, the multiple correlation coefficients (R=.298 and .241) may be considered weak values. Therefore, those results indicated that FPTs would not work very well to predict group membership much better than chance. The percentage of correct group membership predictions, 64.29% (Z=2.343, $P \leq 0.05$), for 4 and 3 test combinations, and 60% (Z=1.645, $P \leq 0.05$) for the SLHT, are significantly different from 50% (Z=1.645, $P \leq 0.05$), the same as chance. However, a 60% likelihood of accurate group inclusion is not very good as a clinical tool. A value of 80% would be more acceptable.

Based on the results of this study, it is suggested that clinicians seeking to determine if a patient has functional deficits secondary to CAI apply the SLHT as their first step of evaluation and assessment. It can be used to quickly evaluate a patient and has some clinical usefulness. Combining three of the FPTs (TIB, FLT, and SEBT) may be applied as the next step for further evaluation. While there is some clinical usefulness in these FPTs, we do not believe the 4 we studied can be used either alone or in combination as the sole determinant of the presence of CAI.

This study is not without limitations. One limitation is that participants might have failed to report their lower extremity injury history or may have reported it inaccurately. Also, another limitation is that possible differences in physical activity level between each individual and the narrow age range utilized may decrease generalizability of results. Further, the multiple correlation coefficient values were classified as “weak association.” Therefore, the use of these tests to identify individuals with CAI should be done with caution and followed up with self-report assessments, the currently used.

Further research is needed to explore establishing FPTs that are better at predicting ankle instability, perhaps by utilizing more frontal-plane and rotational tasks. Also, the definition of “low-intense,” “semi-functional,” or “semi-dynamic” functional tests should be established to classify the intensity of the FPTs, which may affect the ability of a test to determine group membership. FPTs that are correlated with instrumented measures of postural stability may be useful. Future studies may be able to classify the group memberships into Functional Ankle Instability (FAI), Mechanical Ankle Instability (MAI), and Copers and provide clinically relevant “cut-off scores” for determining group membership.

Conclusion

The combinations of 3 or 4 FPTs yielded the same percentage of correctly classified participants into CAI or control groups. However, the SLHT test is almost as effective as the 3-test combination, and may be used in isolation if time constraints are an issue. However, as the predictive ability is not high for any of the tests or test or test combinations, clinicians should follow up with other measuring tools such as self-report or instrumented biomechanical measures if they are available.

CHAPTER 5

SUMMARY

The purpose of this study was to determine which FPTs best identify ankle stability/instability group membership. There was no significant difference between the CAI and control group in performance on any FPTs. However, statistically significant correlations between the TIB and the FLT, and the SLHT and the SEBT were found. Combining 4 FPTs (TIB, FLT, SLHT, and SEBT), combining 3 FPTs (TIB, FLT, and SEBT), and the single SLHT FPT revealed a statistically significant value on the Z-test, indicating better prediction than chance. The results of this study indicated that some FPTs may be used solely or in combination to determine CAI vs. healthy control group membership, but that identification is not much better than chance. In future studies, FPTs need to be classified based on functional demand, and the plane of functional performance, to validate the predictive ability. Also, a larger sample size and a stricter cut-off score for the questionnaire should be considered to prove the better likelihood of accurate group inclusion.

Research Question 1

The first hypothesis was that participants in the control group would have better FPT scores compared to participants with CAI. However, there was no significant difference between the CAI and the control groups in any FPT scores (See Table 2 in Chapter 4). The results of this study do not support most previous literature.[19,79]

The mean time for the SLHT in the CAI group was 16.38 seconds. This was 2.4 seconds longer than the control group, which could be considered as clinically significant even though it was not statistically significant. But, the standard deviations, ±5.54 in the CAI group and ±5.09 in the control group, could be considered as too large to determine if group differences actually existed. A larger sample size should be considered for future studies. Docherty et al.[19] found a positive correlation between the self-reported questionnaires and the SLHT. The SLHT was significantly able to predict ankle instability status.[79] While we did not test this, our results seem to agree that there is a relationship between SLHT performance and presence of CAI. Similar to Sharma[15] and DeMerrit[28], CAI performed worse on the SLHT, supporting our findings, but we did not reach statistical significance. Though not always statistically significantly different, it appears people with CAI consistently perform worse on SLHT compared to control.

Previous research found evidence that the SEBT is a sensitive clinical tool to screen musculoskeletal deficits and impairments in patients with CAI.[17] Reaching distance in patients with CAI was decreased compared to that in healthy participants.[17] However, the results of our study indicated that the posteromedial reach of the SEBT was not a strong clinical tool. The lack of components, other reach directions which are posterolateral and anterior direction, could cause different outcomes. Also, the SEBT should be considered as a lower functional demand test.

The FLT may be a good clinical tool to detect differences between individuals with and without CAI.[35] Hiller et al[35] found that participants in the healthy control group presented better scores on the FLT than participants in the CAI group. In contrast, the results of this study showed no agreement with Hiller's study. There was no significant difference between the CAI and control in the FLT though the CAI group performed worse. With limited studies, it is unclear if FLT performance is worse in CAI, but initial results seem to support it though not always to a level of statistical significance.

Also, participants with history of ankle sprain performed shorter stance time than participants without history of ankle sprain during the TIB.[93] However, there was no significant difference between the groups in the TIB either in this study. Human error such as a time-stopping and error-counting could affect the results. Also, participants may have good balance ability even though they committed more errors in the FLT and balanced a shorter time in the TIB test. Participants may compensate more movements such as lifting part of the foot and shifting their body. Therefore, we have to clarify the errors and strategies to maintain the balance. The effect size (Cohen's *d*) and power (1-*ß*) for the FPTs were reported in Table 6. The effect size for TIB was very small and the effect size of the FLT, SLHT, and SEBT was classified as medium. The strongest effect size was in the SLHT. This relationship seems to indicate that a larger sample size should be considered to establish the predicting of group membership. A total sample size of 95 is required to obtain a large effect size (*d* = 0.75) and power (0.95) in future studies.

Table 5. Power and Cohen's d in Functional Performance Tests

Functional Performance Tests	Power (1-*ß*)	Cohen's *d*	Interpretation
Foot Lift Test (FLT)	0.39	0.41	Medium
Time in Balance Test (TIB)	0.08	0.13	Negligible
Single Leg Hop Test (SLHT)	0.45	0.45	Medium
Star Excursion Balance Test (SEBT)	0.41	0.42	Medium

We did not find differences between groups, though some previous research has. We likely did not find differences because of low power and possibly heterogeneous groups.

Our results were not statistically significant, but our values were going to direction we expected that CAI group performed FPTs worse than control group even though it was not statistically significant.

Research Question 2

The second hypothesis was that a significant correlation existed between the FPT scores. Clark et al[96] found that there were statistically significant relationships between different types of the FPTs (the Single Leg Balance [SLB], Modified Balance Error Scoring System [mBESS], and Modified Star Excursion Balance [mSEBT] tests). However, the strength of association was limited between the FPTs because the FPTs may not evaluate the same components of function, such as strength, balance, and proprioception.[96] Also, the results of the study conducted by Ross et al[97] using static (the single-leg standing test) and dynamic (a jumping landing test) tests revealed that there is no difference between the CAI and control groups during the static test. However, there was a statistical difference between the groups during the dynamic test.[97] The previous research, along with the results from this study, agrees that the static FPTs such as the FLT and TIB were significantly correlated and the FPTs such as the SLHT and SEBT were significantly correlated.[97] Even though a significant correlation between the FPT scores in the CAI and the control groups was anticipated as a hypothesis, the results from this study may be interpreted that each FPT may assess different components of ankle joint function. Indeed, the SLHT and SEBT were significantly correlated and the FLT and TIB were significantly correlated in this study (Table 7) (Figures 1 and 2). One possibility for dividing the FPTs into 2 groups is the different intensities of the FPTs required during performance. Therefore, clinicians should consider the intensity of FPTs when utilizing different FPTs to determine ankle instability group membership.

Table 6. Correlation between Functional Performance Tests in Chronic Ankle Instability and Control group

		Foot Lift Test	Time In Balance Test	Single Leg Hop Test	Star Excursion Balance Test
Foot Lift Test	Pearson Correlation		**-.425***	.079	-.073
	Sig. (2-tailed)		**.000**	.516	.551
Time In Balance Test	Pearson Correlation			-.250	.058
	Sig. (2-tailed)			.037	.631
Single Leg Hop Test	Pearson Correlation				**-.345***
	Sig. (2-tailed)				**.003**
Star Excursion Balance Test	Pearson Correlation				
	Sig. (2-tailed)				

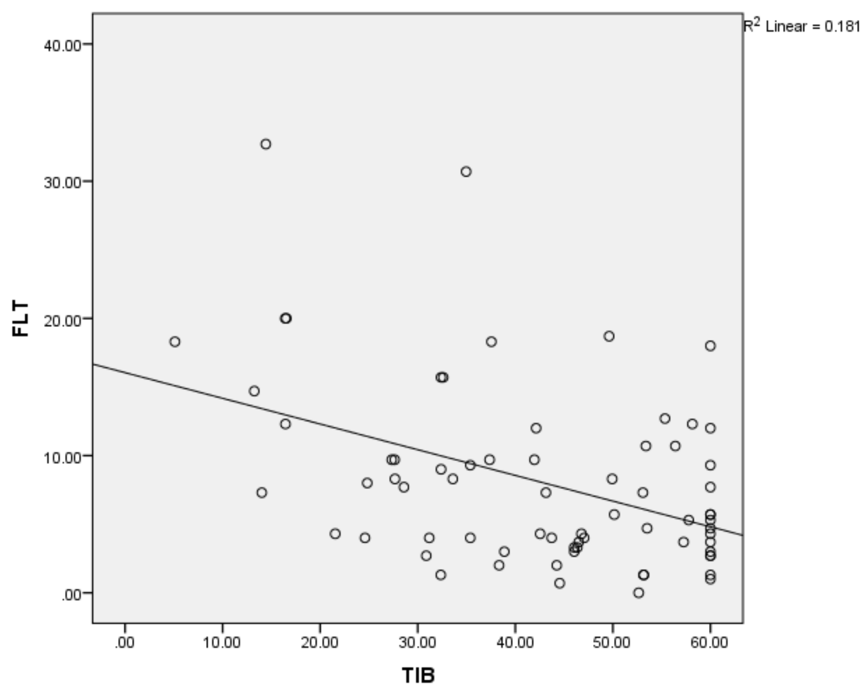

Figure 1. Pearson Correlation between Foot Lift Test (FLT) and Time in Balance Test (TIB)

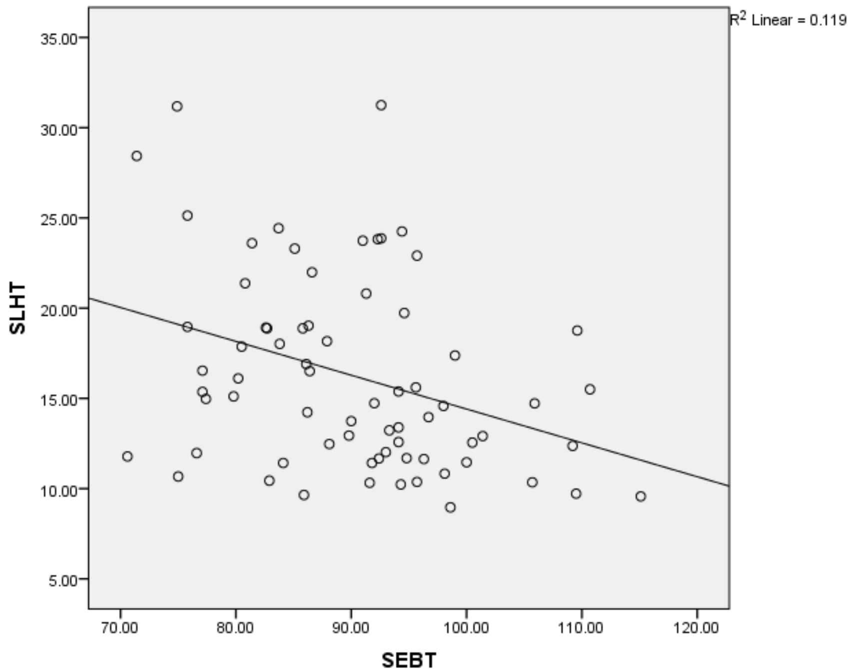

Figure 2. Pearson Correlation between Single Leg Balance (SLHT) and Star Excursion Balance (SEBT) Test

<u>Research Question 3</u>

Finally, we hypothesized that the FPTs would demonstrate good ability to predict group membership. Our study found that combining 4 FPTs (TIB, FLT, SLHT and SEBT) and combining 3 (TIB, FLT, and SEBT) FPTs revealed the highest predictive value. Also, the SLHT showed the highest predictive value as a single FPT. Despite the lack of significant multiple correlation coefficients (R) values using the FPTs, they could be considered to have clinically significant predictive values. The percentage of correct predictions, 64.29% for the 4 and 3 test combinations, and 60% for the SLHT, are significantly different from 50%, or better than chance (See Table 4 in Chapter 4). Ideally, a clinical test should be at least 80% accurate.

Although Demeritt et al[28] reported that there is no difference in performance between the FPTs (Cocontraction, Shuttle Run, and Agility hop test) and CAI, other previous researchers[15,19] have established functional performance deficits in the population with CAI. Though not all of our hypotheses were supported, there are still some clinical implications that may be taken from this study. One possible reason for the lack of significant results could be the nature of the functional tests. Docherty et al[19] found functional performance deficits in patients with functional ankle instability (FAI) while they performed the figure-8 hop and side-hop tests, which required frontal plane movement. However, 3 FPTs (TIB, FLT, and SEBT) in this study were not the frontal-plane functional performance activities. The SLHT was the only test that included frontal-plane functional performance activity in this study. The results of this study also indicated that the SEBT was not a strong clinical tool to predict group membership, even though the SEBT has been validated and shown to be a reliable clinical measuring tool to assess dynamic postural control.[17,78,94,95] This finding may emphasize that the SEBT should be considered as a "low-intense," "semi-functional," or "semi-dynamic" functional test instead of a "dynamic postural stability test." Participants may have experienced less intensity with the SEBT than with other FPTs during the performances. These interpretations may be supported by Clark et al.[98], who found that different types of FPTs may not be consistent in assessing functional performance in a clinical test.

Based on the results of this study, it is suggested that clinicians apply the SLHT as their first step of evaluation and assessment, as they need to quickly evaluate a patient. Combining 3 FPTs (TIB, FLT, and SEBT) may be applied as the next step for further evaluation.

Limitations and Future Directions

This study is not without limitations. One limitation is that participants might have failed to report their lower extremity injury history or may have reported it inaccurately. Also, another limitation is that possible differences in physical activity level between each individual and the narrow age range utilized may decrease generalizability of results. Human error may have resulted in errors associated with timing the FPTs. Further, the multiple correlation coefficient values were classified as “weak association.” Therefore, the use of these tests to identify individuals with CAI should be done with caution and followed up with self-report assessments, the current gold standard.

Future research is needed to explore validating and establishing FPTs with frontal-plane and rotational functional performance activities that may be better able to predict ankle instability. Also, the definition of “low-intense,” “semi-functional,” or “semi-dynamic” functional tests should be established to classify the intensity of the FPTs. Future studies may be able to classify the group memberships into Functional Ankle Instability (FAI), Mechanical Ankle Instability (MAI), and Copers which are relevant subgroups within the CAI umbrella.

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APPENDIX A

Cumberland Ankle Instability Tool (CAIT) Questionnaire

Form 2. Cumberland Ankle Instability Tool

Please mark the ONE statement in EACH question that BEST describes your ankles. SUBJECT ID ______________

	Left	Right
1. I have pain in my ankle		
Never	☐	☐
During sport	☐	☐
Running on uneven surfaces	☐	☐
Running on level surfaces	☐	☐
Walking on uneven surfaces	☐	☐
Walking on level surfaces	☐	☐
2. My ankle feels UNSTABLE		
Never	☐	☐
Sometimes during sport (not every time)	☐	☐
Frequently during sport (every time)	☐	☐
Sometimes during daily activity	☐	☐
Frequently during daily activity	☐	☐
3. When I make SHARP cuts, my ankle feels UNSTABLE		
Never	☐	☐
Sometimes when running	☐	☐
Often when running	☐	☐
When walking	☐	☐
4. When going down the stairs, my ankle feels UNSTABLE		
Never	☐	☐
If I go fast	☐	☐
Occasionally	☐	☐
Always	☐	☐
5. My ankle feels UNSTABLE when standing on ONE leg		
Never	☐	☐
On the ball of my foot	☐	☐
With my foot flat	☐	☐
6. My ankle feels UNSTABLE when		
Never	☐	☐
I hop from side to side	☐	☐
I hop in one spot	☐	☐
When I jump	☐	☐
7. My ankle feels UNSTABLE when		
Never	☐	☐
I run on uneven surfaces	☐	☐
I jog on uneven surfaces	☐	☐
I walk on uneven surfaces	☐	☐
I walk on a flat surface	☐	☐
8. TYPICALLY, when I start to roll over (or "twist") my ankle, I can stop it		
Immediately	☐	☐
Often	☐	☐
Sometimes	☐	☐
Never	☐	☐
I have never rolled over on my ankle	☐	☐
9. After a TYPICAL incident of my ankle rolling over, my ankle returns to "normal"		
Almost immediately	☐	☐
Less than one day	☐	☐
1-2 days	☐	☐
More than 2 days	☐	☐
I have never rolled over on my ankle	☐	☐