

**AN IN-DEPTH EXAMINATION OF STRENGTH IN SUBJECTS WITH
SELF-REPORTED CHRONIC ANKLE INSTABILITY
AND MECHANICAL LAXITY**

by

Shannon Matheny

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment
of the requirements for the degree of Master of Science in Exercise Science

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by

Shannon Victoria Matheny

Approved: _____
Thomas W. Kaminski, Ph.D., ATC, FNATA, FACSM
Professor in charge of thesis on behalf of the Advisory Committee

Approved: _____
William B. Farquhar, Ph.D.
Chair of the Department of Kinesiology and Applied Physiology

Approved: _____
Kathleen S. Matt, Ph.D.
Dean of the College of Health Sciences

Approved: _____
Ann L. Ardis, Ph.D.
Senior Vice Provost for Graduate and Professional Education

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ABSTRACT

Context: Lateral ankle sprains commonly occur within the athletic population. However, athletes who sustain one ankle sprain have a higher risk of recurrent episodes that frequently lead to chronic ankle instability (CAI). CAI is a multifactorial diagnosis that includes mechanical and functional instability components. Mechanical instability generally includes ligamentous laxity, whereas functional instability includes neuromuscular aspects and strength. However, the impact of laxity and CAI on ankle strength remains un. **Objective:** To compare ankle strength (PF, DF, INV and EV) measurements in athletes who have mechanical laxity and who present with reported chronic ankle instability after a history of unilateral ankle sprains. **Design:** Retrospective study. **Participants:** 165 participants including 97 males and 68 females (height = 178.01cm, weight = 78.7 kg, age = 18.5 years). **Interventions:** An injury history questionnaire and Cumberland Ankle Instability Tool (CAIT) were administered to determine the number of previous ankle sprains and the presence of self-reported CAI. Laxity of the ankle joint was determined using a portable ankle arthrometer measuring anterior displacement in millimeters and inversion rotation in degrees. Strength was measured using a Kin Com isokinetic dynamometer and peak torque for the four different ankle motions were recorded. **Main Outcome Measures:** The independent variable was group status as determined by either (1) ankle instability (CAIT scores) and (2) ankle laxity (arthrometry

measurement). The dependent variables are peak torque strength measures, concentric (CON) and eccentric (ECC) in two velocities (30°/sec & 120 °/sec), in all ankle motions. **Results:** 24 subjects (14.54%) had both anterior and INV/EV laxity and 74 of the 165 participants (44.84%) had self-reported CAI in their injured ankle. The laxity group presented with less PF CON strength at 30°/sec ($t=-2.567$, $p=.011$) and EV CON strength at 120 °/sec ($t=-2.137$, $p=.034$) than those who did not have laxity. A trend toward significance was seen for ECC ($t=-1.905$, $p=.059$) and CON PF at 120 °/sec ($t=-1.852$, $p=.066$). No significance was found between those with or without CAI and their strength measurements. **Conclusion:** Plantar flexion and eversion strength was significantly less in those without laxity compared to their contralateral, uninjured ankle, exhibiting a need for specific rehabilitation of the specific muscle groups. Even though no significant differences were found with CAI, significance was found with gender and right versus left ankle, exposing that our understanding of CAI as a diagnosis and its relationship with strength is not fully understood.

Chapter 1

INTRODUCTION

Ankle and foot injuries account for more than three million emergency room visits annually.¹ While this number is extremely large, an estimated 55% of those who sustain an ankle sprain do not seek medical attention nor treatment.¹⁻⁵ When examining the sport population, the second most commonly injured area of the body is the ankle joint.⁶ If these ankle injuries are ignored and not treated correctly, reinjury is likely to occur, as the ankle sprain recurrence rate has been reported to be as high as 80% in high-risk sports.^{1,7} The conundrum from a clinical perspective is that despite proper treatment intervention and quality care, the recurrence rate is still alarmingly high. Compounding the high recurrence rate is the fact that most of these individuals (32-47%) continue to suffer from chronic symptoms.^{1,7-9} These residual symptoms and recurrent sprains cause patients to be involved in a continuous cycle of symptoms and reinjury.³

One of the residual and potentially long-lasting symptoms is mechanical laxity; caused by the ligamentous damage to the ankle after injury. The amount of separation to the lateral ligaments affects the extent of pathologic laxity of the lateral ankle.³ Laxity, or objective mechanical instability, can last from six weeks to one year after injury, with some cases extending multiple years.^{6,10} As mechanical laxity is thought to be a potential cause of residual symptoms at the ankle, this evidence suggests that those with a history of ankle sprains may be at risk for recurring injury for months, if not years, after an initial ankle sprain.^{6,10}

While mechanical instability can be present after an ankle injury, it has been suggested that mechanical instability is rarely the cause of functional instability, which is defined as recurrent sprains, episodes of “*giving-way*”, pain, swelling, or decreased function after an initial ankle sprain.^{5,11,12} Functional instability, in conjunction with mechanical instability has been implicated in producing symptoms associated with chronic ankle instability (CAI).^{3,5} Multiple studies have reported that those with CAI have increased ligament laxity, alluding to the mechanical instability factor of the diagnosis.^{10,13,14} In order to more clearly differentiate athletes with and without CAI, clinicians use the Cumberland Ankle Instability Tool (CAIT).¹⁵ Correctly identifying athletes with CAI is an important first step in enabling clinicians the ability to develop intervention programs aimed towards decreasing articular degeneration of the joint by increasing physical activity; thereby, lowering the risk of osteoarthritis in the ankle joint later on in life.^{10,16}

Because mechanical and functional instability are related to recurring ankle injury and long-lasting symptoms, typical treatment attempts to correct both.^{3,5} Strength training is one method aimed at reducing the likelihood of reinjury and prolonged symptoms. Athletes rely on muscular co-contraction, specifically eccentric control during sports; therefore, the ability for muscles around the ankle to co-contrast and efficiently dissipate forces is critical after an ankle sprain.¹⁷ Previous research examining the relationship between muscle weakness and CAI has noted that those with CAI had significantly higher eccentric peak torque dorsiflexion/plantar flexion ratio than a control group; most likely associated with a reduction in plantar flexion eccentric torque.^{13,18,19} Reinjury to the ankle may also occur when the inversion/eversion torque ratio is altered,

indicating muscle weakness.^{18,20,21} Ankle strengthening programs may restore normal inversion/eversion strength, which could possibly assist with CAI and limit reoccurrence.¹⁸ However, it remains unclear the direct relationship between strength and CAI.

While deficits in proprioception have been implicated as a cause of recurrent ankle sprains, in those with mechanical instability its deficits in strength that appear to be most worrisome. Groth et al.²² suggested that sufficient muscle strength, specifically that provided by the peroneals, is important in patients with mechanical instability to overcome the recurrent symptoms associated CAI.^{20,22} Ligamentous injury can also inhibit dynamic stabilization of the lateral ankle produced by the neuromuscular system.³ Furthermore, others report that muscle weakness in combination with a proprioception deficiency causes CAI, and the “*giving-way*” symptoms associated with it.^{11,20,23} Functional insufficiencies of the ankle were shown, in one study, to be the cause for bilateral differences within the group with CAI.¹³ More concisely, functional instability stems from muscular deficiencies in addition to proprioceptive deficiencies.⁵ The rehabilitation process, which includes a focus on strengthening the ankle joint, could be valuable in lowering the risk of CAI and residual the symptoms associated with it.

When focused solely on a homogenous group of subjects who have suffered unilateral ankle sprains, the question remains whether or not mechanical laxity and/or CAI exist. Furthermore, it remains to be seen as to whether or not there are associated deficits in ankle muscle strength in both of these subgroups. Therefore, the purpose of this study was to determine how many subjects within the athletic population classify as having CAI or laxity. Furthermore, this study aims to compare peak torque strength

measures of those with or without CAI and strength measures of those with or without laxity.

Chapter 2

METHODS

2.1 Participants

Data files from a total of 553 student-athletes from the National Collegiate Athletic Association (NCAA) Division- I sports including football, men's basketball, women's basketball, men's lacrosse, women's lacrosse, men's soccer, women's soccer, field hockey, and volleyball were examined. Each subject provided consent to participate using the university approved document (UDIRB#1131714-11). Prior to participation, all subjects completed an ankle study inclusion questionnaire detailing ankle injury history. Participants in this study included only those subjects with a history of unilateral ankle sprains, resulting in a total of 165 subjects (97 males, 68 females, height = 178.01cm, weight = 78.7 kg, age = 18.5 years).

Males	97
Females	68
Height (cm)	178.01±10.3
Weight (kg)	78.7±17.1
Age (years)	18.5±.73

2.2 Procedures

2.2.1 Subject Groupings (CAIT Scores)

The Cumberland Ankle Instability Tool (CAIT)¹⁵ was used to determine CAI status in those subjects identified as having unilateral ankle sprain history. The validity and reliability of the CAIT in discriminating those with CAI has been established.¹⁵ Recently, Wright et al.⁸ has utilized a more accurate cutoff score of 25 (sensitivity of 96.6% and specificity of 86.8%) in differentiating those with CAI. Therefore, in our study, the CAIT cutoff score of equal to, or less than 25, was utilized to signify those with CAI. For this particular grouping characteristic, we identified a total of 74 subjects with CAI, unilaterally. The opposite uninjured ankle would then serve as the control for all subsequent data analysis.

2.2.2 Subject Groupings (Ankle Laxity)

Ankle laxity measurements were derived using our previously described testing protocol with an instrumented portable ankle arthrometer (Blue Bay Research Inc, Navarre, FL)²⁴ The laxity versus no laxity groupings were determined using differences of ≥ 3 mm for anterior displacement and ≥ 3 degrees of inversion rotation compared to the uninjured ankle.²⁵⁻²⁷ Twenty-four subjects matching both criteria were used for comparison using the strength measurements between the involved and uninvolved ankles

2.3 Strength Testing

The Kin Com 125 AP (Isokinetic International, Chattanooga, TN) isokinetic dynamometer was used to assess peak torque (PT) for all four ankle motions (plantar flexion [PF], dorsiflexion [DF], inversion [INV], eversion [EV]). Kin Com dynamometers allow for precise and reliable measurement and storage of data from isokinetic, isotonic, and isometric muscular actions.^{28,29} The isokinetic procedures described below were derived from those previously performed by Kaminski et al. and Morrison and Kaminski.³⁰

INV/EV ankle strength was tested with subjects seated in the dynamometer chair with hip and knee slightly flexed and the lower leg secured using the universal stabilizer attachment. The foot (shoe) was securely fastened into the ankle INV/EV footplate attachment. A total of 45° of INV/EV motion was tested. Using the overlay protocol function on the Kin Com, both concentric (CON) and eccentric (ECC) muscle actions were tested at velocities of 30°/sec and 120°/sec. A total of three maximal repetitions were performed at each speed. Peak torque (PT) was then derived from each of the CON and ECC torque curves. Gravity compensation was not necessary for this testing position.

PF/DF ankle strength was tested with subjects seated in dynamometer chair with hip flexed to 90° and knee completely extended. The thigh was held down to the dynamometer chair using the thigh stabilizer attachment. The foot (shoe) was securely fastened into the ankle PF/DF footplate attachment. A total of 45° of PF/DF motion was tested. For PF testing the start position was in 10° of DF pushing downward (CON) toward the stop angle of 35° of PF. For DF testing the opposite occurred whereas the

motion started at 35° of PF moving upward (CON) into DF until they stopped at 10 degrees of DF. Using the overlay protocol function on the Kin Com, both CON and ECC muscle actions were tested at velocities of 30°/ sec and 120°/ sec. A total of three maximal repetitions were performed at each speed. Peak torque was then derived from each of the CON and ECC torque curves. Gravity compensation was necessary for this testing position.

2.4 Statistical Analysis

The primary independent variable in this study is group status as determined by either (1) ankle instability (CAIT scores) and (2) ankle laxity (arthrometry measurement). The dependent measure will include the isokinetic strength measurements involving the PT values for all four ankle motions (PF, DF, INV, EV) both concentrically and eccentrically at the two velocities (30°/ sec and 120°/ sec). The CON and ECC muscle actions will be analyzed separately.

The subjects satisfying the unilateral ankle sprain inclusion criteria were used to qualify those subjects partitioned off into the CAI and ankle laxity groups. Differences in strength between the affected ankle and the uninjured control ankle were examined utilizing a random coefficient model with a scaled identity error structure. This model included the strength measures as the dependent variables and the primary variables of ankle instability and ankle laxity as independent variables. Sex, injured ankle, and limb were also included in the analysis to control for potential covariates. All models were run using SPSS Version 22.0 (SPSS, Inc., Chicago, IL USA). By using this analysis, it was

possible to compare all variables simultaneously. Values that were three or more standard deviations past the mean were considered outliers and eliminated. Also, subjects that did not have all necessary data for one depended variable were excluded from that analysis. These subjects were included in all other analyses.

Chapter 3

RESULTS

The data set consisted of strength values from a total of 165 participants including 97 males and 68 females (height = 178.01cm, weight = 78.7 kg, age = 18.5 years). Of the 165 participants analyzed, 24 subjects (14.54%) had both anterior and INV/EV laxity. Seventy-four of the 165 participants (44.84%) had self-reported CAI in their injured ankle at the time of testing.

3.1 Laxity

When controlling for side (right or left), injured ankle, gender, and CAI, participants in the laxity group presented with less EV CON strength at 120 °/sec ($t=-2.137$, $p=.034$) than those without laxity (Figure 1). PF CON strength at 30°/sec was also significantly less in the laxity group compared to the group without laxity ($t=-2.567$, $p=.011$) (Figure 2). A trend toward significance was seen for ECC ($t=-1.905$, $p=.059$) and CON PF at 120 °/sec ($t=-1.852$, $p=.066$) when comparing ankle joint laxity groups. Specifically, participants with laxity exhibited lower strength values than those without laxity (Table 1). CON and ECC INV and DF strength values were not significantly different between laxity groups at either velocity (Table 2).

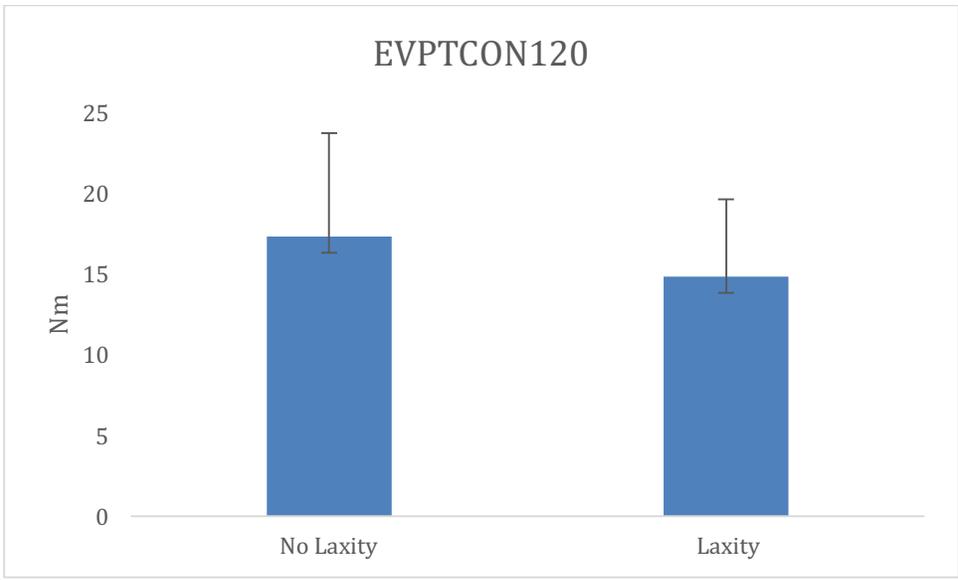


Figure 1 Laxity and no laxity groups during eversion peak torque concentric strength at 120°/ sec

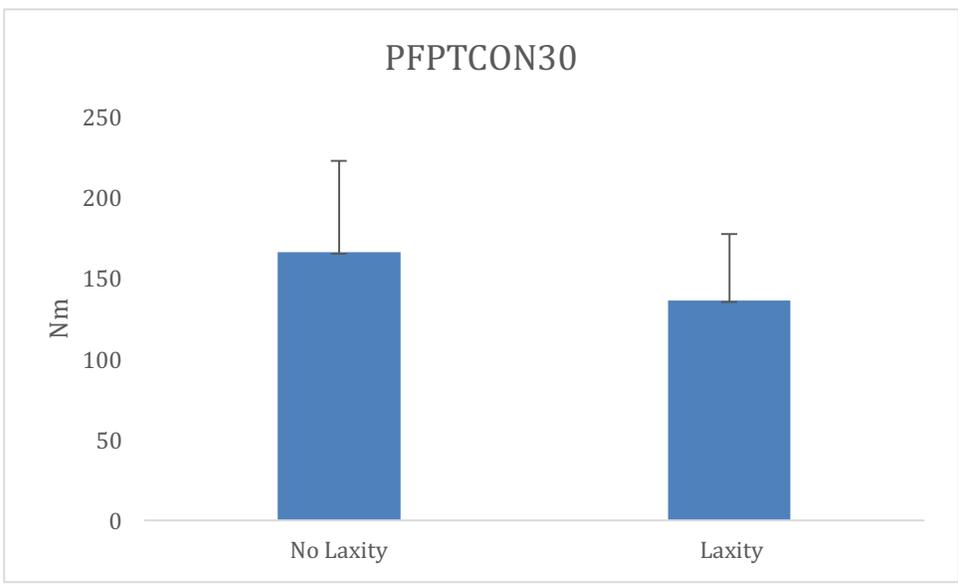


Figure 2 Laxity and no laxity groups during plantar flexion peak torque concentric strength at 30°/ sec

Table 2 Average peak torque strength measures of CAI, no CAI, Laxity, and no Laxity

Groups	PFPTCON30	PFPTECC30	PFPTCON120	PFPTECC120
No CAI	164.4 ± 57.6	240.3 ± 82.9	102.7 ± 47.4	227.4 ± 83.5
CAI	161.99 ± 50.4	239.5 ± 84.7	99.3 ± 38.4	216.1 ± 76.8
No Laxity	166 ± 56.5	242 ± 83.6	103.2 ± 46.3	227.2 ± 83.0
Laxity	136.1 ± 41.0	215.6 ± 75.0	86 ± 31.2	194.2 ± 62.5
	DFPTCON30	DFPTECC30	DFPTCON120	DFPTECC120
No CAI	45.7 ± 17.9	69.3 ± 23.7	29 ± 13	70.3 ± 23.6
CAI	45.6 ± 14.7	67.5 ± 21.8	27.5 ± 10	68.5 ± 19.8
No Laxity	45.5 ± 17.3	68.5 ± 23.1	28.8 ± 12.5	69.8 ± 23.0
Laxity	48.1 ± 15.9	74.6 ± 25.6	27.3 ± 11.0	70.8 ± 20.8
	INPTCON30	INPTECC30	INPTCON120	INPTECC120
No CAI	23.2 ± 8.5	28.3 ± 12.2	17.2 ± 6.6	27.9 ± 12
CAI	23.2 ± 8.8	27.2 ± 12.1	16.6 ± 5.6	28.0 ± 12.2
No Laxity	23.3 ± 8.6	27.9 ± 12.1	17.2 ± 6.4	28 ± 12.0
Laxity	21.2 ± 7.6	29.9 ± 14.0	16 ± 6.3	26.9 ± 12.1
	EVPTCON30	EVPTECC30	EVPTCON120	EVPTECC120
No CAI	23.0 ± 7.6	29.5 ± 12.3	17.3 ± 6.5	29.4 ± 11.2
CAI	22.7 ± 6.7	28.5 ± 10.1	16.8 ± 6.0	27.7 ± 9.6
No Laxity	23.0 ± 7.4	29.3 ± 12	17.3 ± 6.4	29.1 ± 10.9
Laxity	21 ± 6.8	28.4 ± 10.3	14.8 ± 4.8	27.2 ± 10.2

Table 3 Significant measures based on ankle motion and velocity

SIGNIFICANCE	PF	DF	INV	EV
<i>CON 30</i>	M > F, R > L, Not Lax > Lax	M > F	M > F	M > F, R > L
<i>ECC 30</i>	M > F, R > L	M > F	M > F	M > F
<i>CON 120</i>	M > F, R > L Trend: Not Lax > Lax	M > F, R > L	M > F, R > L	M > F, R > L, Not Lax > Lax
<i>ECC 120</i>	M > F, R > L, Trend: Not Lax > Lax	M > F, R > L	M > F	M > F

M = Male, F = Female, R = Right Ankle, L = Left Ankle, Lax = Laxity group. PF CON 30 (t=-2.567, p=.011) and EV CON 120 (t=-2.137, p=.034) both showed significance wherein non lax group had higher strength values.

3.2 CAI, Gender, and Limb Side

When controlling for side (right or left), injured ankle, gender, and laxity, no significant findings were observed for the strength values between those with or without self-reported CAI. All CON and ECC strength measurements in males were significantly greater than those in females ($p < .001$) (Table 3). Furthermore, the right limb PF strength measures were greater when compared to the left limb. This was also true for DF (CON and ECC at 120°/ sec), INV CON (120°/ sec), and CON EV (30°/ sec and 120°/ sec).

Table 4 Average peak torque strength measures of males and females based on ankle motion and velocity

AVERAGE STRENGTH (PT)	PF	DF	INV	EV
CON 30	M: 191.6	54.4	26.8	26.5
	F: 126.7	33.3	18.2	17.8
ECC 30	M: 277.4	82.7	32.8	34.5
	F: 187.1	49.8	21.6	22
CON 120	M: 120.7	34.5	19.8	19.9
	F: 75.7	20.5	13.3	13.4
ECC 120	M: 259.9	82.8	32.5	34
	F: 176.3	52.1	21.5	22
M = MALE, F = FEMALE, PT = PEAK TORQUE				

Chapter 4

DISCUSSION

The purpose of this study was to compare CON and ECC ankle strength (PF, DF, INV and EV) measurements in athletes who have mechanical laxity and self-reported chronic ankle instability after a history of unilateral ankle sprains. The results of the current study showed that those who present with mechanical laxity have lower PF CON strength at 30°/sec and EV CON measures at 120°/sec than subjects without mechanical laxity. Further findings showed no significant strength differences in those with and without CAI at the time of testing. However, gender and ankle side (right and left) do appear to affect isokinetic strength measurements.

Our first specific aim examined the percentage of an athletic population that presented with CAI or laxity. The results of our study showed that 44.84% of participants suffer from self-reported CAI. Although this percentage did not support our specific hypothesis of 32%, it is an accurate depiction of the current literature reporting that CAI is present in 32% to 47% of those who have suffered from at least one lateral ankle sprain.^{8,9,27} With a population exclusively of collegiate athletes, the results show that a high activity level may not prevent residual symptoms. Therefore, current rehabilitation practices may not be sufficient even in a population where corrective treatment is often available. Furthermore, our hypothesis of 20% of the subjects categorized within the laxity group was incorrect, based on our results of 14.54% having greater than 3 mm of anterior displacement and 3mm INV/EV rotation of the uninjured

from the injured ankle. Our original hypothesis of 20% was based on a combination of symptoms, including mechanical laxity usually present with CAI. We inferred that the amount within an athletic population would follow the trend of prevalence seen with CAI. However, it is interesting to note that our results, although different from our hypothesis, are similar to the typical amount of healthy population who present with asymmetric laxity (11%).² Therefore, we could argue that mechanical laxity may be a naturally occurring trait that is not necessarily associated with CAI.

Even though mechanical laxity may occur naturally, it still appears to affect strength values in athletes with a previous unilateral ankle sprain.^{1-3,13,17} The current study has shown PF CON at 30°/sec and EV CON at 120°/sec to decrease in the ankle with laxity, with a trend toward significance of decreased PF CON and ECC at 120°/ sec. Ligaments hold a joint in the correct placement wherein surrounding musculature, when activated, contract more efficiently. Based on this idea, ligamentous laxity should inhibit efficient muscular co contraction. Witchalls et al.⁷ found functional performance deficits in those laxity of the ankle joint. Therefore, explosiveness and agility deficits may be observed because of proprioceptive issues. Based on our results, we can suggest that the reduced strength of the plantar flexors and evertors of the ankle in athletes who have suffered a unilateral ankle sprain are one potential cause of these performance deficits. Our results may affect clinical treatment by targeting specific musculature, specifically the gastrocnemius, soleus, and peroneals, during rehabilitation.

Our study found no significance between those with or without CAI and strength. One theory to explain the results of this study is the dynamical systems theory.³¹ Ankle sprain can alter biomechanics because injured athletes limit movement due to acute

symptoms, reducing the degrees of freedom for the joint to move, which may appear bilaterally. If recurring ankle sprains affect an athlete bilaterally, comparing an athlete's injured ankle to their uninjured ankle may not show those results. This may translate into injury rehabilitation by focusing less on asymmetric exercises and may encompass more of the kinetic chain. Not finding significance with CAI and strength at the ankle alludes to compensation, based on the dynamical systems theory, at sites other than the ankle because of injury.³² This utilization of a kinematic strategy may change the rehabilitation process to look at the limb and body working in tandem, instead of focusing on the injured ankle.

Furthermore, the grouping for CAI and no CAI for this study were determined based on a self-reported questionnaire, with the total participants who classified as having CAI at 44.84%, thus supporting other literature. The CAIT, although showing high sensitivity and specificity, is not without flaws. For example, this tool does not provide a way to control for copers, those with CAI, not suffering from clinical symptoms. Also, the cutoff score of 25 was utilized for this study based on a recalibration by Wright et al.⁸; however, this score may have limited the amount of subjects with CAI that were included. In the future, it would be wise to use the CAIT in adjunct with another diagnostic questionnaire such as the Functional Ankle Instability Questionnaire (FAIQ), Ankle Instability Instrument (AII) or the Ankle Joint Functional Assessment Tool (AJFAT) to have a confident inclusion of those with CAI.^{33,34}

The results of our study revealed a significant decrease in the strength measures of female participants compared to the male participants. Specifically, females were 59.4-67.8% weaker than males, when comparing strength in all ranges of motions at both

velocities. These data align with previous literature indicating that stronger musculature in males compared to females translates to the ankle joint.³⁵ Despite previous ankle sprains, we see that gender affects strength. Clinically, the results argue for a more targeted treatment practice, specifically working to strengthen the plantar flexors and evertors of the ankle. Also, male and female athletes should have differing progression of strength training protocols because of difference in muscular complexities.

Although this study provides a unique focus on the factors related to ankle sprains, it is not without its limitations. Lack of limb dominance as a variable is one such limitation. However, previous literature is ambiguous on the effect of limb dominance as an limb dominance being an intrinsic factor for ankle injury.³⁶ Some studies show, for other lower extremity injury that limb dominance is arbitrary in predicting or effecting injury occurrence.^{37,38} Therefore, we specifically controlled for right and left limb, and injured versus uninjured limb and did not collect limb dominance. To measure laxity, we used a portable instrumented arthrometer. It has been shown that arthrometry is more reliable than manual testing. However, throughout the collection of our data, two separate arthrometers and multiple testers were utilized.^{39,40} This poses the issue of intra-reliability. We attempted to control for this limitation by comparing bilaterally within subjects, instead of between subjects. Thus, all comparative variables were derived from the same arthrometer and tester. Finally, the groupings of CAI, were formed based on a self-reported questionnaire. Although the sensitivity and specificity for identifying CAI based on the CAIT is high (sensitivity of 96.6% and specificity of 86.8%), it is a subjective questionnaire and compliance may not always be controlled for.⁸

The results of this study show that athletes who have mechanical laxity of their injured ankle exhibit deficits in EV and PF strength. Based on these results, clinicians should continue to be cognizant of lingering laxity differences in athletes with a previous ankle sprain and enhance focus on PF and EV strength during the rehabilitation process. The observation that strength is not affected by CAI grouping indicates a possible need for a more accurate diagnostic tool than the CAIT. Further research should attempt to determine how more targeted rehabilitation and treatment plans affect those with mechanical laxity and CAI after unilateral ankle sprain.

REFERENCES

1. Gribble PA, Delahunt E, Bleakley CM, Caulfield B, Docherty CL, Fong DT, Fourchet F, Hertel J, Hiller CE, Kaminski TW, McKeon PO, Refshauge KM, van der Wees P, Vicenzino W, Wikstrom EA,. Selection criteria for patients with chronic ankle instability in controlled research: A position statement of the international ankle consortium. *J Athl Train.* 2014;49(1).
2. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train.* 2002;37(4):364-375.
3. Hubbard TJ, Cordova M. Mechanical instability after an acute lateral ankle sprain. *Arch Phys Med Rehabil.* 2009;90(7):1142-1146.
4. Guillo S, Bauer T, Lee JW, et al. Consensus in chronic ankle instability: Aetiology, assessment, surgical indications and place for arthroscopy. *Orthop Traumatol Surg Res.* 2013;99(8 Suppl):S411-9.
5. van Rijn RM, van Os AG, Bernsen RM, Luijsterburg PA, Koes BW, Bierma-Zeinstra SM. What is the clinical course of acute ankle sprains? A systematic literature review. *Am J Med.* 2008;121(4):324-331.e6.
6. Fong DT, Hong Y, Chan LK, Yung PS, Chan KM. A systematic review on ankle injury and ankle sprain in sports. *Sports Med.* 2007;37(1):73-94.
7. Witchalls JB, Newman P, Waddington G, Adams R, Blanch P. Functional performance deficits associated with ligamentous instability at the ankle. *J Sci Med Sport.* 2013;16(2):89-93.
8. Wright CJ, Arnold BL, Ross SE, Linens SW. Recalibration and validation of the Cumberland ankle instability tool cutoff score for individuals with chronic ankle instability. *Arch Phys Med Rehabil.* 2014;95(10):1853-1859.

9. Braun BL,. Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. *Arch Fam Med.* 1999;8(2).
10. Hubbard TJ, Hicks-Little CA. Ankle ligament healing after an acute ankle sprain: An evidence-based approach. *J Athl Train.* 2008;43(5):523-529.
11. Freeman MA. Instability of the foot after injuries to the lateral ligament of the ankle. *J Bone Joint Surg Br.* 1965;47(4):669-677.
12. Delahunt E, Coughlan GF, Caulfield B, Nightingale EJ, Lin CW, Hiller CE. Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Med Sci Sports Exerc.* 2010;42(11):2106-2121.
13. Hubbard TJ, Kramer LC, Denegar CR, Hertel J. Contributing factors to chronic ankle instability. *Foot Ankle Int.* 2007;28(3):343-354.
14. Hertel J, Denegar CR, Monroe MM, Stokes WL. Talocrural and subtalar joint instability after lateral ankle sprain. *Med Sci Sports Exerc.* 1999;31(11):1501-1508.
15. Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The Cumberland ankle instability tool: A report of validity and reliability testing. *Arch Phys Med Rehabil.* 2006;87(9):1235-1241.
16. Harrington KD. Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. *J Bone Joint Surg Am.* 1979;61(3):354-361.
17. Kaminski TW, Hartsell HD. Factors contributing to chronic ankle instability: A strength perspective. *J Athl Train.* 2002;37(4):394-405.

18. Abdel-aziem A, Draz A. Chronic ankle instability alters eccentric eversion/inversion and dorsiflexion/plantarflexion ratio. *J back musculoskelet rehabil.* 2014;27:47--53.
19. Arnold BL, Linens SW, de la Motte SJ, Ross SE. CON evertor strength differences and functional ankle instability: A meta-analysis. *J Athl Train.* 2009;44(6):653-662.
20. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J Athl Train.* 2002;37(4):487-493.
21. Terrier R, Rose-Dulcina K, Toschi B, Forestier N. Impaired control of weight bearing ankle inversion in subjects with chronic ankle instability. *Clin Biomech (Bristol, Avon).* 2014;29(4):439-443.
22. Groth AT, Guyton GP, Schon LC. Lateral ankle ligament injuries in athletes: Diagnosis and treatment. *Oper techn sport med.* 03;18(1):18; 18-26; 26.
23. Kim KJ, Kim YE, Jun HJ, et al. Which treatment is more effective for functional ankle instability: Strengthening or combined muscle strengthening and proprioceptive exercises? *J Phys Ther Sci.* 2014;26(3):385-388.
24. Liu K. Increased frequency of ankle sprain does not lead to an increase in ligament laxity. *Clin J Sport Med.* 2013;23(6):483; 483-487; 7.
25. Hirai D. Severity of functional and mechanical ankle instability in an active population. *Foot Ankle Int.* 2009;30(11):1071; 1071-1077; 7.

26. Johannsen A. Radiological diagnosis of lateral ligament lesion of the ankle: A comparison between talar tilt and anterior drawer sign. *Acta Orthop Scand*. 1978;49(3):295-301.
27. Konradsen, L., Magnusson, Peter,. Increased inversion angle replication error in functional ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2000;8(4):246-251.
28. Kaminski T. Eversion strength analysis of uninjured and functionally unstable ankles. *J Athl Train*.. 1999;34(3):239; 239-245; 45.
29. Kaminski T, Perrin D, Mattacola C, Szczerba J, Bernier J. The reliability and validity of ankle inversion and eversion torque measurements from the kin com II isokinetic dynamometer. Updated 1995.
30. Morrison K. Foot characteristics in association with inversion ankle injury. *J Athl Train*. 2007;42(1):135; 135-142; 42.
31. Davids, Keith, Glazier, Paul, Araújo, Duarte, Bartlett, Roger,. Movement systems as dynamical systems: The functional role of variability and its implications for sports medicine. *Sport Med*. 2003;33(4):245-260.
32. Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., Delahunt, E.,. Single-leg drop landing motor control strategies following acute ankle sprain injury. *SMS Scand J Med Sci Sport*. 2015;25(4):525-533.
33. Donahue M, Simon J, Docherty CL,. Critical review of self-reported functional ankle instability measures. *Foot Ankle Int*. 2011;32(12):1140-6.
34. Hubbard, T. J., Kaminski, T.W. Kinesthesia is not affected by functional ankle instability status. *J Athl Train*. 2002;37:481-486.

35. Hicks A. Sex differences in human skeletal muscle fatigue. *Exerc Sport Sci Rev.* 2001;29(3):109; 109-112; 12.
36. Fong DT, Chan YY, Mok KM, Yung PSh, Chan KM,. Understanding acute ankle ligamentous sprain injury in sports. *Sports Med Arthrosc Rehabil Ther Technol.* 2009;1.
37. Weinhandl JT. Influence of sex and limb dominance on lower extremity joint mechanics during unilateral land-and-cut manoeuvres. *J Sports Sci.* 2016(4):1; 1-9; 9.
38. Brown AM, Zifchock RA, Hillstrom HJ. The effects of limb dominance and fatigue on running biomechanics. *Gait Posture.* 2014;39(3):915-919.
39. Wilkin E, Hunt A, Nightingale E, Munn J, Kilbreath S, Refshauge K. Manual testing for ankle instability. *Man Ther.* 2012;17(6):593--596.
40. Kovalski JE, Heitman RJ, Gurchiek LR, Hollis JM, Liu W, Pearsall AW, 4th. Joint stability characteristics of the ankle complex after lateral ligamentous injury, part I: A laboratory comparison using arthrometric measurement. *J Athl Train.* 2014;49(2):192-197.

Appendix

LITERATURE REVIEW

Ankle and foot injuries account for more than 3 million ER visits annually.¹ A large number of these visits are due to lateral ankle sprains. Traditional treatment of lateral ankle sprains includes rest, ice, compression, and elevation during the initial inflammatory response phase. As the swelling and pain subside, strength training has been suggested to return the ankle to normal function.² However, many of those who sustain an ankle sprain do not receive this care as an estimated 55% are not evaluated and go untreated.¹⁻⁵ Since this population is untreated, they may experience strength deficits that lead to residual symptoms after an injury episode. If these strength deficits are still present after returning to play, it may lead to an increased chance of recurring ankle sprains.

The physiological response of tissue to an injury is the same regardless of severity. A sprained ankle typically presents with swelling and possible discoloration due to damage to elastic fibers of the ligaments. Scar tissue replaces the original tissue, altering the stiffness and tissue mechanical properties. Functionally, an ankle sprain typically presents with pain that increases upon movement and bearing weight. As pain decreases through the healing process, joint function should return to a normal state relatively equal to baseline. Depending on the severity of injury, this return to normal ankle function may return to normal in days or months. However, return to full function does not indicate that the ankle has fully healed. Instead, an extremely high risk for recurrent injury still

exists, but it has yet to be determined what factors may reduce susceptibility to subsequent injury.³

Despite treatment received, residual and chronic symptoms after a lateral ankle sprain occur in 32-74% of those with a history of ankle sprains.^{1,6} Therefore, current rehabilitation techniques appear to be inadequate. Ultimately the failure to perform adequate rehabilitation is a likely factor of the extremely high (80%) recurrence rate of ankle sprains in high-risk sports.¹ Understanding the factors that may lead to recurrent injuries may be a valuable step into enhancing the rehabilitation process and lowering the risk for secondary injuries and residual symptoms.

In sports, the ankle is the second most commonly injured area of the body.⁷ A wide variety of sports, such as cheerleading (26.2% of all injuries), volleyball (45.6%), soccer (21.2%), basketball (15.9%), and track and field (39.2%) have a high incidence of ankle sprains.^{7,8} The prevalence and long-term effects of ankle sprains makes knowing the pathological effects important so that correct treatment can be administered. Since the biggest risk factor for sustaining an ankle sprain is a previous injury to the same joint,³ gaining a better understanding of the deficiencies caused by injury will allow clinicians to lower the reinjury rate by altering and enhancing rehabilitation programs. In the following literature review, the sections presented are: Anatomy, Chronic Ankle Instability, and Strength.

Anatomy

The ankle is a complex system that is susceptible to injury. Ligamentous restraints, muscular systems, and congruent articular surfaces work together to contribute

to ankle stability.⁹ The main articulation of the ankle is the talocrural joint, which is also known as the “mortise”.⁹ The talocrural joint consists of the articulation of the talus with the lateral and medial malleoli, which allows for plantar flexion and dorsiflexion of the ankle.¹⁰ During weight bearing, with the ankle in neutral, the articular surfaces act as the primary stabilizers. The interosseous, transverse, and tibiofibular ligaments, which bind the tibia and fibula together, provide secondary stabilization.⁹ The joint is relatively unstable when plantar flexed because the trochlea (rounded articular surface of the talus) rotates anteriorly, which decreases contact area and articular stability posteriorly.⁹ The subtalar joint is the articulation of the talus and calcaneus, which produces the functional movements of supination and pronation around its single, oblique axis.¹⁰ The calcaneofibular ligament (CFL), anterior talofibular ligament (ATFL), and posterior talofibular ligament (PTFL) stabilize the joint on the fibular side, which a lateral ankle sprain is defined as the total or partial disruption of a combination of the three structures.^{9,11,12} The weakest ankle ligament involved in approximately 73% of lateral ankle sprains, is the ATFL.^{7,11,13} The ATFL, primarily prevents anterior talar translation, which injury to the ligament creates laxity as shown with the anterior drawer test.¹⁰ While the ATFL prevents specific instability, a previous cadaver study has shown the coordination of the CFL and ATFL to prevent talar tilting.¹⁴ This cadaver analysis shows that secondary support can stabilize the lateral ankle in case of injury to the ATFL. The surrounding musculature provides dynamic lateral ankle support which supplements the static ligamentous structures. Support to the lateral ankle, and prevention of injury to the lateral ligaments is suggested to come from the strength of peroneus longus and brevis muscles.^{15,16} These muscles run on the lateral aspect of the ankle joint, posterior to the

malleolus and add to the stabilization of the joint as a proprioceptive neuromuscular system. These deficits lead to muscle weakness and add to the fundamental causes of Chronic Ankle Instability (CAI), or “giving way”.^{15,17,18} These factors work along with the presence of mechanical laxity to illicit the diagnosis. In this study, we will look at how much strength contributes to both CAI and mechanical laxity.

Chronic Ankle Instability

Previous history of ankle sprain is a common predisposition for recurring lateral ankle sprains.³ After sustaining an ankle sprain, the presentation of residual symptoms, such as episodes of ankle joint “giving way”, pain, swelling, and decreased function can occur. If symptoms are present, patients meet the standards for a condition called Chronic Ankle Instability (CAI).^{4,8} While the exact mechanism of CAI development is unclear, mechanical and functional instability are two complications that likely lead to the presentation of its signs and symptoms.^{3,4} Recurrent ankle sprains cause a multitude of physiological issues. CAI can not only limit physical activity, it can also lead to articular degeneration of the joint and increase the risk of osteoarthritis in the ankle joint.^{19,20} CAI is also frequently interchangeable with the term Functional Ankle Instability (FAI), which specifically points to the subjective aspects of chronic ankle injury.

Functional Ankle Instability (FAI)

A history of recurring clinical instability, which includes episodes of recurrent sprains or “giving way”, can be defined as functional instability. Freeman (1965) suggested that mechanical instability of the ankle is rarely the only cause, initially, of

functional instability symptoms.¹⁸ This subjective aspect of functional instability is the presentation of pain and other symptoms such as “giving way” or persistent sprains.¹² In a previous study, the group of subjects with CAI were shown to have bilateral differences both with strength and performance due to functional instability.²¹ The feeling of “giving way” reported by patients could be a repercussion of muscle weakness, mechanical laxity, or a combination of both. Overall, functional instability appears to stem from muscular deficits, possibly due to neural inhibition.^{3,4} Some patients may not have functional instability, even with a history of recurring ankle sprains and possible ligamentous pathology. These patients do not suffer from the subjective functional symptoms and are labeled as copers.¹

Since functional instability is related to modifiable muscular and neural factors, clinicians attempt to correct it with rehabilitation after injury. However, van Rijn, et al. reported, that in some cases, patients continued to experience episodes of functional instability after three years.² Ankle strength training is the primary method used to treat strength deficiencies, but other factors associated with CAI, such as muscle activation and a lack of neural drive may impact strength in athletes with a previous ankle sprain. Therefore, understanding the relationship between CAI and strength may help clinicians to understand deficits to address in rehabilitation and encourage further rehab for patients who have repeated instances of giving-way or instability.

Quantifying Chronic Ankle Instability (CAI)

The subjectivity of FAI is derived from a patient report to determine whether a patient actually has CAI. Therefore, a valid and reliable tool is needed for its

measurement. Three subjective forms, the Functional Ankle Instability Questionnaire (FAIQ), Ankle Joint Functional Assessment Tool (AJFAT), and Cumberland Ankle Instability Tool (CAIT) are typically used to determine the status of CAI in a patient with a previous ankle sprain. Of these tools, only the CAIT has been shown to be a reliable tool for determining CAI.²² The CAIT is clinically valuable due to the inclusion of functional variables independent from the subject's other ankle. This isolates the condition of the subject's left and right ankle individually and allows for a more specific diagnostic criterion.

Concurrent validity of the CAIT has been tested against the Lower Extremity Functional Scale (LEFS), which is a lower-limb reference standard using a 10cm visual analog scale to measure multiple variables including perceived exertion and pain.^{22,23} Using the LEFS as a comparison, a CAIT score of 27.5 was the discrimination score for FAI. This cut-off score would indicate that athletes with a score of 27 or lower most likely have CAI, whereas a score of 28 or higher would likely not have CAI.^{24,22} A further exploration of the CAIT indicates that a recent study by Wright et al has shown that a cutoff score of 25 may be more sensitive (96.6%) and specific (86.6%) in differentiating those with and without CAI.²⁵ Therefore, the authors suggest that the cut-off score of 27.5 should be lowered in order to correctly include those with CAI.²⁵ For the purposes of this study, a cutoff score of 25 will be used. Using this score provides a clear differentiation of those who could be non-copers and classifies as them as copers, due to the lack of reported symptoms. Multiple studies have reported that people with CAI present with more ligament laxity than uninjured controls.^{19,21,26} These deficiencies of the ankle joint can lead then to a continuation of recurring episodes.³

Mechanical Instability

Mechanical instability is defined as excessive laxity of the talocrural joint during instrumented (arthrometry or stress radiography) or manual stress that exceeds the normal expected physiological or accessory motion of the ankle.⁸ This excessive laxity is often attributed to ligamentous pathology from ankle injury, which can compromise ankle joint stability and result from a pathological deformity of the lateral ligaments. Hypermobility of the ankle, such as inversion and anterior laxity, can contribute to CAI.²¹ For example, since inversion rotational laxity is greater in those with a history of ankle sprains, the excess laxity could contribute to chronic instability.²⁷ Athletes with a lateral ankle sprain display greater inversion and anterior laxity, shown clinically through talar tilt and anterior drawer tests, in addition to posterior laxity, compared to healthy controls.^{10, 28} Damage to these ligaments creates instability of the ankle joint as a whole; however, eversion mobility is prevented by other structures unaffected by a normal ankle sprain. Laxity inherited from injury typically takes at least six weeks and up to one year to return to normal, potentially leading to excess joint movement and subsequent injury.^{5,19} If laxity does not return to normal, it may affect injury rates and severity of subsequent injury. In this study, we will be using an ankle arthrometer to determine joint laxity since manual testing has shown to have poor inter-rater reliability.²⁴

Although mechanical laxity may be a risk factor in the development of CAI, it cannot be fully corrected by conservative rehabilitation. Furthermore, mechanical instability, does not necessarily present with clinical symptoms. Instead, neuromotor capabilities and muscle strength, specifically of the peroneal tendons, can compensate to provide the support lacking from ligamentous structures. Therefore, patients with

mechanical instability may or may not subjectively notice symptoms.¹² Mechanical laxity provides a predisposition for recurrence because of its inability to stabilize the joint. The other stabilizers of the ankle joint, including the muscular system, may need to be a focus in order to reestablish function.

Functional outcomes of mechanical laxity are long-lasting and affect performance. Since laxity remains eight weeks after an initial lateral ankle sprain, further pathology of the ankle joint may occur if an athlete returns to his/her normal activity level without corrective surgery.⁵ Returning to previous activity level with laxity present would limit the static restraint in the ankle and likely place the athlete at a greater risk for re-injury. A loss of static restraint is not the only reason that athletes may be at a greater risk of injury when laxity is still present after a lateral ankle sprain. Explosive power, agility and proprioception deficits have all been previously associated with laxity of the ankle ligaments.⁶ Since ligaments provide proprioceptive information when they are stretched, shown with knee ligamentous studies, laxity could be a longer reflexive response, leading to muscular inefficiency.²⁹ This theory has been confirmed by Witchalls et al., who found that individuals with CAI are associated to have deficits in muscular performance.⁶ If muscular performance is decreased and static restrains are compromised because of laxity, an athlete with previous injury will likely have another roll-over episode, leading to further injury. Furthermore, ligamentous injury can also inhibit dynamic stabilization of the lateral ankle produced primarily by the neuromuscular system.³ The amount of damage to the lateral ligaments affects the extent of pathologic laxity of the lateral ankle.³ Therefore, when evaluating the severity, the

amount of laxity or strength of surrounding musculature may point to the likelihood of recurrence.

Strength

Athletes rely on muscular co-contraction, with both eccentric and concentric control during sports. This ability to co-contract muscles could be impaired due to the lack of the muscular ability to dissipate forces in an efficient way, brought on by impaired neural mechanisms.³⁰ These impaired mechanisms are essentially a result of muscle inefficiency and this weakness has been associated with FAI.³¹

Strength of specific muscles, being a large component of rehabilitation is important to evaluate when it comes to recurring ankle sprains. Peroneus longus and brevis stabilize the lateral ankle and protection against excessive supination of the rearfoot by eccentric contraction.^{3,32} In a study by Willems et al., those with CAI are weaker, both concentrically and eccentrically, in eversion than the control subjects.¹⁵ The result of this study adds to the evidence of eversion weakness as a condition of CAI and therefore a valuable factor in predicting recurring ankle injuries.^{15,33} It has also been shown that reinjuries occur to the ankle when the inversion/eversion torque ratio is altered. This same concept is shown by Amaral de Noronha et al., where there was a higher peak torque generated by invertors than evertors in injured ankles at 120°/s.^{30,34} The eversion strength of the ankle joint may be a valuable variable to analyze when it comes to ankle injury and the likelihood reoccurrence.

Although forces in the frontal and transverse planes typically cause lateral ankle sprains, sagittal plane strength is still important because the ankle is most stable in a

dorsiflexed position.¹⁰ An altered proportion of strength with the agonist and antagonist muscle groups surrounding the ankle joint may be reasonable indicator of CAI. Two separate studies, Hubbard et al in 2007 and Abdel-aziem et al in 2014, found that those in the group with CAI had significantly higher eccentric peak torque of dorsiflexion/plantar flexion ratio than the control group. This is due to a decrease of eccentric torque with plantar flexion.^{21,30} However, dorsiflexion eccentric peak torque was no different between normal ankles and those with CAI when tested at both angular velocities, suggesting that the muscles responsible for plantar flexion are primarily altered in people with CAI and/or previous injury.³⁰ Essentially, this evidence implies that weakness during plantar flexion may be a predictor of CAI, leading to an increased chance of recurrent injury.

Willems (2002) hypothesized that subjects with higher levels of muscle strength are more protected from repetitive ankle sprains among CAI symptoms.¹⁵ However, conflicting results exist regarding this possible correlation between ankle strength and CAI. The theory of peroneal muscle weakness as a component of CAI was confirmed in Tropp's study with the use of an isokenetic dynamometer.³⁵ However, Lentell et al. found no differences of muscular strength in chronically unstable ankles, either isometrically or isokinetically.³⁶ Generally speaking, muscular strength of the ankle may be a contributor of ankle stability, but other structures may be important as well. Various studies argue that ankle stability may be improved by a combination of proprioceptive and strengthening exercises,^{15,17} which supports the need for rehabilitation to prevent recurring ankle injury.

Summary

Strength training could be a valuable part of ankle rehabilitation programs because it allows the muscles to increase force output and prevent ankle instability. Ankle strengthening programs, specifically isotonic, may restore normal eversion/inversion strength, which could possibly assist in limiting CAI after an initial ankle sprain.³⁰ However, it remains unclear how a combination of mechanical and functional instability can impact strength values. Determining this relationship can lead to progressive, patient-centered rehabilitation which could treat people with ankle instability differently based on subjective symptoms and objective signs. These new rehabilitation protocols could then be used for people with CAI and limit the number of recurrent ankle sprains.

REFERENCES

1. Gribble PA, Delahunt E, Bleakley CM, Caulfield B, Docherty CL, Fong DT, Fourchet F, Hertel J, Hiller CE, Kaminski TW, McKeon PO, Refshauge KM, van der Wees P, Vicenzino W, Wikstrom EA. Selection criteria for patients with chronic ankle instability in controlled research: A position statement of the international ankle consortium. *J Athl Train*. 2014;49(1):121-127.
2. van Rijn RM, van Os AG, Bernsen RM, Luijsterburg PA, Koes BW, Bierma-Zeinstra SM. What is the clinical course of acute ankle sprains? A systematic literature review. *Am J Med*. 2008;121(4):324-331.
3. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364-375.
4. Guillo S, Bauer T, Lee JW, Takao M, Kong SW, Stone JW, Mangone PG, Molloy A, Perera A, Pearce CJ, Michels F, Tourne Y, Ghorbani A, Calder J. Consensus in chronic ankle instability: Aetiology, assessment, surgical indications and place for arthroscopy. *Orthop Traumatol Surg Res*. 2013;99S:S411-S419.
5. Hubbard TJ, Cordova M. Mechanical instability after an acute lateral ankle sprain. *Arch Phys Med Rehabil*. 2009;90(7):1142-1146.
6. Witchalls JB, Newman P, Waddington G, Adams R, Blanch P. Functional performance deficits associated with ligamentous instability at the ankle. *J Sci Med Sport*. 2013;16(2):89-93.
7. Fong DT, Hong Y, Chan LK, Yung PS, Chan KM. A systematic review on ankle injury and ankle sprain in sports. *Sports Med*. 2007;37(1):73-94.

8. Delahunt E, Coughlan GF, Caulfield B, Nightingale EJ, Lin CW, Hiller CE. Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Med Sci Sports Exerc.* 2010;42(11):2106-2121.
9. Moore, Keith L., Dalley, Arthur F. *Clinically Oriented Anatomy.* 4th ed. Philadelphia: Lippincott Williams & Wilkins; 1999.
10. Starkey, C., Brown, Sara D., Ryan, Jeffrey L. *Examination of orthopedic and athletic injuries.* 3rd ed. Philadelphia: F.A. Davis Co.; 2010.
11. Martin RL, Davenport TE, Paulseth S, Wukich DK, Godges JJ, Orthopaedic Section American Physical Therapy Association. Ankle stability and movement coordination impairments: Ankle ligament sprains. *J Orthop Sports Phys Ther.* 2013;43(9):A1-40.
12. Groth AT, Guyton GP, Schon LC. Lateral ankle ligament injuries in athletes: Diagnosis and treatment. *Oper Tech Sports Med.* 03;18(1):18; 18-26; 26.
13. Brostroem L. Sprained ankles. I. anatomic lesions in recent sprains. *Acta Chir Scand.* 1964;128:483-495.
14. Cass JR, Settles H. Ankle instability: In vitro kinematics in response to axial load. *Foot Ankle Int.* 1994;15(3):134-140.
15. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J Athl Train.* 2002;37(4):487-493.
16. Glick JM, Gordon RB, Nishimoto D. The prevention and treatment of ankle injuries. *Am J Sports Med.* 1976;4(4):136-141.
17. Kim KJ, Kim YE, Jun HJ, Kim YE, Jun HJ, Lee JS, Ji SH, Ji SG, Seo TH, Kim YO. Which treatment is more effective for functional ankle instability: Strengthening or

- combined muscle strengthening and proprioceptive exercises? *J Phys Ther Sci*. 2014;26(3):385-388.
18. Freeman MA. Instability of the foot after injuries to the lateral ligament of the ankle. *J Bone Joint Surg Br*. 1965;47(4):669-677.
19. Hubbard TJ, Hicks-Little CA. Ankle ligament healing after an acute ankle sprain: An evidence-based approach. *J Athl Train*. 2008;43(5):523-529.
20. Harrington KD. Degenerative arthritis of the ankle secondary to long-standing lateral ligament instability. *J Bone Joint Surg Am*. 1979;61(3):354-361.
21. Hubbard TJ, Kramer LC, Denegar CR, Hertel J. Contributing factors to chronic ankle instability. *Foot Ankle Int*. 2007;28(3):343-354.
22. Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The Cumberland Ankle Instability Tool: A report of validity and reliability testing. *Arch Phys Med Rehabil*. 2006;87(9):1235-1241.
23. Binkley JM, Stratford PW, Lott SA, Riddle DL. The lower extremity functional scale (LEFS): Scale development, measurement properties, and clinical application. *Phys Ther*. 1999;79(4):371-383.
24. Wilkin E, Hunt A, Nightingale E, Munn J, Kilbreath S, Refshauge K. Manual testing for ankle instability. *Man Ther*. 2012;17(6):593--596.
25. Wright CJ, Arnold BL, Ross SE, Linens SW. Recalibration and validation of the cumberland ankle instability tool cutoff score for individuals with chronic ankle instability. *Arch Phys Med Rehabil*. 2014;95(10):1853-1859.
26. Hertel J, Denegar CR, Monroe MM, Stokes WL. Talocrural and subtalar joint instability after lateral ankle sprain. *Med Sci Sports Exerc*. 1999;31(11):1501-1508.

27. Kovaleski JE, Heitman RJ, Gurchiek LR, Hollis JM, Liu W, Pearsall AW, 4th. Joint stability characteristics of the ankle complex after lateral ligamentous injury, part I: A laboratory comparison using arthrometric measurement. *J Athl Train*. 2014;49(2):192-197.
28. Cordova ML, Sefton JM, Hubbard TJ. Mechanical joint laxity associated with chronic ankle instability: A systematic review. *Sports Health*. 2010;2(6):452-459.
29. Krogsgaard MR, Dyhre-Poulsen P, Fischer-Rasmussen T. Cruciate ligament reflexes. *J Electromyogr Kinesiol*. 2002;12(3):177-182.
30. Abdel-aziem A, Draz A. Chronic ankle instability alters eccentric eversion/inversion and dorsiflexion/plantar flexion ratio. *J Back Musculoskelet Rehabil*. 2014;27:47--53.
31. Arnold BL, Linens SW, de la Motte SJ, Ross SE. Concentric evertor strength differences and functional ankle instability: A meta-analysis. *J Athl Train*. 2009;44(6):653-662.
32. Ashton-Miller J. What best protects the inverted weightbearing ankle against further inversion? Evertor muscle strength compares favorably with shoe height, athletic tape, and three orthoses. *Am J Sports Med*. 1996;24(6):800-9.
33. Terrier R, Rose-Dulcina K, Toschi B, Forestier N. Impaired control of weight bearing ankle inversion in subjects with chronic ankle instability. *Clin Biomech (Bristol, Avon)*. 2014;29(4):439-443.
34. Amaral De Noronha M, Borges NG, Jr. Lateral ankle sprain: Isokinetic test reliability and comparison between invertors and evertors. *Clin Biomech (Bristol, Avon)*. 2004;19(8):868-871.

35. Tropp H. Pronator muscle weakness in functional instability of the ankle joint. *Int J Sports Med.* 1986;7(5):291-294.
36. Lentell G, Katzman LL, Walters MR. The relationship between muscle function and ankle stability. *J Orthop Sports Phys Ther.* 1990;11(12):605-611.