**The pathomechanics of changes in joint position sense following lateral inversion ankle sprains**

By Christopher Ritter

The sprained ankle is one of the most frequently occurring musculoskeletal injuries associated with physical activity with an estimated incidence rate of 2.15 per 1,000 people each year in the United States.1 This rate is greatest for persons between 15 to 19 years of age with a respective incidence rate of 7.2 per 1,000.1 Ankle sprains are estimated to account for 1.6 million office visits and 8,000 hospitalizations each year in the US with sprains resulting in ligamentous damage representing one of the most common musculoskeletal impairments treated by physical therapists.2–4 Almost half of all ankle injuries occur during athletic activity, most commonly in sports involving frequent change of direction and jumping such as basketball, volleyball, football, and soccer.1,5 A systematic review of sports injuries from 1977 to 2005 found that the ankle was the most commonly injured body part in 24 of 70 different sports reviewed.3 Specifically, the ankle sprain was the major ankle injury in 33 of 43 sports.3

An estimated 83% of ankle sprains are lateral inversion sprains in which an external inversion force applies stress to the ligaments of the talocrural, subtalar joints, and inferior tibiofibular joints.6–8 The lateral ligament complex is comprised of three main ligaments including the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL) and the posterior talofibular ligament (PTFL), with the ATFL being the most commonly injured with an estimated two-thirds of all injuries isolated to this ligament.6 The CFL is the second most commonly injured and almost always occurs in the presence of injury to the ATFL.6 The ATFL is the weakest of the three ligaments and most compromised when the ankle is in supination with combined plantar flexion, internal rotation, and inversion, coupled with relative external rotation of the lower leg.6,8

Risk factors for ankle sprain can be separated into extrinsic and intrinsic factors. Extrinsic factors include specific sports or at risk behaviors, level of competition, shoe type, playing surface, and use of external supports such as tape or ankle brace.1,9–11 Intrinsic risk factors include age, weight, body mass index (BMI), gender, height, flexibility, limb dominance, aerobic fitness level, limb girth, muscle strength, reaction time, postural stability, anatomical alignment, foot type, flexibility, previous injury and inadequate rehabilitation.1,9–11 The greatest predictive factor for lateral inversion ankle sprains is the presence of a previous ankle sprain with rates of re-injury estimated to be between 50-78%.6,12–15 An estimated 30-59% of persons who experience recurrent ankle sprains will go on to report residual symptoms, disability, diminished physical activity, and, or functional impairment.12 Continued symptoms, “giving way”, and recurrent injuries have been termed chronic ankle instability (CAI).16 CAI has been attributed to two components of instability including mechanical instability and functional instability.17

Mechanical instability includes ankle joint motion which is greater than normal physiological limits resulting from ligamentous laxity or damage following sprain.17 Recent definitions of mechanical instability include pathological laxity, arthrokinematic impairments, degenerative joint disease, and synovial changes.8 Functional instability is a more complex concept involving joint motion within normal physiological limits but beyond voluntary or involuntary control due to changes in the sensorimotor system following injury.17 Freeman and Wyke demonstrated that different mechanoreceptors in ankle ligaments and joint capsules of cats relay information about joint position and movement.18 Recent histological studies of human collateral ankle ligaments have confirmed the presence of the four typical types of mechanoreceptors described by Freeman and Wyke.18,19 These four include Ruffini corpuscles (type I, low threshold, slowly adapted), Pacinian corpuscles (type II, low threshold, rapidly adapted), Golgi tendon organs (type III, low threshold, slowly adapted), and free nerve endings (type IV, nociceptive).19,20 Interestingly, both the distribution and morphology of these receptors in human collateral ankle ligaments were different than previous reports of animal tissue.19 These differences in morphology may indicate a more complicated role of proprioceptive functioning in humans and the increased relative number of Pacinian corpuscles may indicate preferential high velocity motion sense.19 Freeman introduced the concept of functional instability in 1965 along with the underlying theory of de-afferentiation following ankle sprain.17 De-afferentiation refers to the interruption of afferent signals from ligament and joint capsule mechanoreceptors following injurious tensile stress to these tissues and resulting in proprioceptive deficits responsible for functional instability.17 According to Freeman’s theory or articular de-afferentiation, damage to these joint receptors leads to lack of afferent proprioceptive signals communicating the joint position in space which leads to supination without reflexive or volitional corrective response of the peroneals to evert the ankle back into a neutral position.17 Other mechanoreceptors located in skin, fascia, synovial tissue, and muscle tissue also contribute to proprioception in the form of position sense, sense of movement, and sense of force.21,22

Proprioception is a term which can have many connotations, being both used to strictly refer to afferent signals used to relay information of body position and orientation in space and more generally to represent a complex multi-level interaction between the conscious and unconscious sense of and ability to control one’s body in space.17,21,23 The study of proprioceptive changes is also complex and confounded by the lack of ability to control and account for many variables in a system with redundant yet differentiated contributions.21 Within the more strictly afferent definition, proprioception is thought to consist of joint position sense, sense of movement, and sense of force. Of these, joint position sense is the most commonly tested in research related to ankle injury. Joint position sense represents a more discretely measurable component of proprioception, and has been researched extensively in relation to lateral inversion ankle injury and reinjury.4

Investigators have used three major approaches to measure joint position sense including: threshold of perceptible movement, ability to replicate contralateral joint position, and ability to replicate joint position through return to previous position with the same ankle (ipsilateral). Of these, ipsilateral joint position replication is the most frequently utilized measure in research related to ankle injury. Contralateral methods are used less frequently in part due to the confounding influence of proprioception within both left and right limbs needed to complete this measure.

One of the earliest studies to examine this question was conducted by Glencross and Thornton and published in 1981.24 In this design, the experimenters measured the subjects’ abilities to actively reproduce a passively determined ankle position along the spectrum of dorsiflexion (DF) and plantar flexion (PF).24 The study found that previously injured ankles were less accurate at this task with statistically significant increased error in active reproduction of the position.24 It is important to note that the positional measurements were garnered using manual goniometry without account for the validity of this method.24,25

A well designed study by MT Gross, published in 1988, set out to answer this question with careful consideration of active versus passive assessments of joint position in sprained and non-sprained ankles.25 For active assessment, the subjects were asked to move their ankle to reproduce a position which was previously achieved passively along the inversion-eversion spectrum of ROM.25 For passive assessment, the experimenter moved the subject’s ankle until the subject verbally indicated it was in the previously achieved position.25 This design examined previous theories of the different mechanisms of passive joint receptors versus active muscle receptors on joint position sense. The results of the experiment did not demonstrate significant differences in total error (TE) between sprained and non-sprained ankles for either active or passive assessment of joint position.25 There was a trend of increased TE for passive joint position assessment in sprained vs. non-sprained ankle.25 Although this trend was not statistically significant, this may have been the result of power limitations from the small sample size.25 Significant interaction between comparison of the passive and active assessments were observed with passive judgements having degreased TE in comparison to active judgements for non-sprained ankles.25 These differences may reflect the different contributions of articular mechanoreceptors to joint angle and muscle receptors to joint motion.25 Furthermore, the unexpected results seen in the contralateral healthy ankle with improved active judgement and impaired passive judgement relative to the control group, offer two possible explanations. This may represent differences present in the injured and contralateral ankle subjects prior to injury or this may indicate the presents of central processing adaptations following unilateral sprain which impact the contralateral ankle.25

In 1988, Garn and Newton published a study which utilized the threshold of perceptible movement method of measuring joint position sense in sprained and non-sprained ankles of persons with a history of multiple unilateral sprains with no current effusion or sprain in the past 30 days.26 This study used a kinesthesiometer to move ankles from neutral to 5 degrees of PF at 0.3˚/sec over 15 seconds and the subjects were asked to respond yes or no to indicate if they detected the movement.26 Trials were also conducted in which the ankle was not moved to test for true and false negatives.26 Using Luce’s Choice theory, the sensitivity to detect this movement was calculated and shown to be statistically significantly decreased for sprained ankles.26

In a 1998 article, Konradsen et al. investigated changes in joint position sense in acute grade II and III ankle sprains at 1, 3, 6, and 12 weeks.27 This experiment utilized passive ipsilateral inversion replication of 10˚, 15˚, and 20˚ inversion with a movement rate of 2˚/sec.27 The mean error was calculated for all three positions and compared to the healthy non-sprained contralateral ankle.27 The mean differences in error in the sprained ankles compared to the non-sprained ankles were 2.5˚ at week 1, 1.9˚ at week 3, 1.1˚ at week 6, and 1.1˚ at week 12.27 Additionally, the relative deficit in joint position sense was not correlated to pathological joint laxity, indicating that these changes were not due to mechanical instability.27

In 1999, Holme et al. published a study which examined the effects of rehabilitation on several factors including position sense, strength, postural sway, and re-injury risk following acute ankle sprains.28 This study utilized an active reproduction assessment method and did not detect a statistically significant difference in position sense for injured versus uninjured ankles at either 6 weeks or 4 months for both the control and training groups.28 The training group did demonstrate superior joint position sense to the control group at 6 weeks and 4 months for both injured and uninjured ankles.28 Interestingly, the improvement in the position sense between 6 weeks and 4 months was greatest in the injured ankles which received rehabilitative training.28 Furthermore, during 12 months after the injury, only 7% of the training group suffered re-injury, but 29% of the control group suffered reinjury.28 This study highlights the importance of supervised rehabilitation with focus on balance recovery in the potential to prevent re-injury, even though the findings on joint position sense were not statistically significant or consistent with previous experiments.

A 2010 systematic review with meta-analysis authored by Munn et al. found significant differences in both passively measured (mean difference=0.7˚) and actively measured (mean difference=0.6˚) joint position sense in persons with CAI. This indicates the potential contribution of joint position sense deficits involved in CAI.

Much of the variability in research involving measures of joint position sense following ankle injury or in the presence of CAI may be attributed to methodological differences in the way joint position sense is measured. A 2010 meta-analysis including 10 studies, examined six key methodological variables involved in testing joint position recognition differences observed in persons with CAI.4

The first key methodological variable examined was the study design group comparison.4 Of the 10 studies examined, 1 study compared ankles with CAI to normal contralateral ankles, 5 studies compared CAI ankles to ankles of different persons in a control group, and 4 studies performed both contralateral and control group comparisons. The pooled results of each group comparison design demonstrated moderate effect sizes with confidence intervals (CI’s) which did not cross zero, indicating that both methods were suitable to identify significant deficits in joint position recognition in ankles with CAI.4 More complex interactions observed in studies which utilized both methods of comparison indicate the presence of central changes within the sensorimotor systems of persons with unilateral CAI which impact health contralateral limbs.4 For this reason between group comparisons offer a higher level of precision and are therefore recommended.4

Starting position was a second methodological variable investigated with most studies starting in the neutral position.4 Pooled results of starting in the neutral position or moving into midrange to end range plantar flexion resulted in moderate effect size (0.51) with narrow CI’s indicating an optimal method.4 Furthermore, plantar flexion is of particular interest given its involvement in the mechanism of injury with lateral inversion ankle sprains.

The two possible repositioning methods compared were active and passive repositioning. In active repositioning the subject uses his or her muscles to move the ankle into a previously established position. In passive repositioning, the ankle is moved through the range manually by the experimenter or an external machine such as a kinesiometer until the subject indicates the previously established position has been reached. Both active and passive methods resulted in pooled results to indicate significant differences in ankles with CAI but active methods had larger pooled effect sizes.4 Active methods may also allow for involvement of motion sense and mechanoreceptors within musculotendinous structures which would not be seen in truly passive methods.

Another interesting methodological variable examined was the testing range of motion or directions in which the ankles were moved in. Given their significance in relation to mechanism of injury, plantar flexion and inversion were the most frequently tested ranges with in the 10 studies. The largest effect sizes with the greatest precision were demonstrated throughout these ranges and in both directions.4 End-range dorsiflexion also demonstrated a moderate effect size with narrow CI’s but more studies are needed which test dorsiflexion and eversion to rule out potential type II errors.4

Movement velocity represents the speed at which subjects are passively moved through range of motion or allowed to actively move to reposition. Smaller movement velocities of 2˚/sec, 4˚/sec, and 5˚/sec were best able to identify true differences in ankles with CAI, but as velocity decreases, all errors increase. Methods which use faster movement velocities have demonstrated decreased threshold to movement and increased consistency with the theory that muscle spindles may provide added afferent information.4,29

The final methodological variable examined was the data-reduction method.4 The data reduction method represents the way in which the experimenters combined the data from multiple tests to create numerical values which could be analyzed statistically. The most common method used by the 10 studies reviewed was mean absolute error, in which the distance or angle of error in either direction from the target position was averaged for all trials in that position or range of motion. The mean absolute error was also found to yield moderated effects and provide the greatest precision, and therefore is recommended by the authors.4

This meta-analysis concluded that persons with CAI consistently demonstrate joint position recognition deficits and that these measures are appropriate tools for identifying kinesthetic deficits associated with CAI.4 Pooled results indicate that between-group comparisons starting from a neutral position and moving into plantar flexion or inversion at a rate of less than 5˚/second with active repositioning, were the most sensitive and precise methods for detecting joint position recognition in persons with CAI The authors also made other specific recommendations for the measurement methodology which are included in Appendix A.

Changes in joint position sense have also been evaluated in terms of the ability to predict future ankle injuries within prospective studies.15 A 1997 study by Payne et al. found changes in inversion and dorsiflexion to be predictive of future ankle injury as measured by active ipsilateral position replication.13 A 2005 study by Willems et al. that deficits of 11˚ error in inversion joint position sense measured through passive ipsilateral replication were predictive of future ankle injuries sustained by 159 female physical education students.14 Other factors including reduced dorsiflexion range of motion and increased postural sway have also demonstrated predictive ability for ankle sprains and it is likely that joint position sense deficits are merely one factor among many others.15 Further studies are needed which better control for the influence and interaction of multiple factors to better understand the contribution of joint position sense to injury.

One theory involving the contribution of joint position sense deficits to recurrent injury in persons with CAI, is that this lack of awareness leads persons with CAI to allow their ankle to be in a more compromised position during activities, leading to increased risk of injury. This is supported by the findings of an increased ankle inversion positioning during the transitional loading phase of walking observed in persons with CAI.30,31 Other studies evaluating the biomechanics of persons with CAI have found similar inversion positioning changes with jump landing, which is one of the most common mechanisms of lateral inversion ankle sprains, and running.32,33 It should be acknowledged that many studies to date examine differences in persons with functional or chronic ankle instability in comparison to health contralateral limbs or healthy control subjects. While changes in joint position sense have been demonstrated in persons with functional and chronic ankle instability, all differences in persons with CAI are not necessarily attributable to altered joint position sense alone. Given the available research, which supports the role of joint position sense deficits seen in persons with CAI, and as predictive variables of re-injury, there are grounds to focus research on potential interventions aimed at improvement of joint position sense.

Most interventions which focus on improvement of proprioception following lateral inversion ankle sprains utilize the more general definition of proprioception with outcome measures that assess sensorimotor function including postural control, reflex reactions, drop landings, and gait analysis. There are fewer experiments which examine the potential for interventions to have impacts on the more strict definition of proprioception pertaining only to measures of joint position sense and joint motion sense. An underlying assumption of experiments with the former operation definition of proprioception is that improvements in these neuromuscular outcome measures can be attributed at least in part to effects on the impaired feed-back system proposed by Freeman.17,21

A 2015 systematic review including 7 studies which evaluated the effectiveness of proprioceptive training on the prevention of ankle sprains, found interventions involving use of wobble boards, and balance without visual feedback were effective in the reduction of ankle sprain injuries.5 This preventative effect was demonstrated in both persons with and without previous history of ankle sprain.5 These studies did not include specific measures of afferent signals of position in space and the term proprioception was used in the more general sense.

True measures of afferent signals themselves are difficult, but measurements of changes in joint position sense can provide insight to potential responses to treatment interventions. A 2008 study, which implemented a 12 week biomechanical ankle platform system (BAPS) training demonstrated significant improvement in joint position sense in persons with FAI.34 It should be noted that the methods for measurement of joint position sense with a demonstrated improvement of both active (1.1˚ ) and passive (1.2 ˚) reduction in error for ipsilateral reproduction of position.34 While there is no consensus of what constitutes a clinically relevant amount of improvement in joint position sense, previous studies have indicated that an inversion error of 7˚ would represent a 5 mm drop in the lateral border of the foot, which is enough to create an external inversion moment capable of causing a lateral inversion ankle sprain.34,35 The observed improvements in joint position sense also correlated to improvements in postural stability as measure by center of pressure excursion during both eyes open and eyes closed conditions.34 Another intervention aimed at controlling joint position to prevent lateral inversion ankle sprains is the use of external support through bracing or taping.

A 2000 study of cross country athletes found that both external ankle bracing and active warmup decreased the inversion angle replication error in athletes with functionally stable ankles.35 A 2008 Cochrane review which included 14 randomized trials found a significant reduction in the number of ankle sprains following use of external ankle supports in the form of semi-rigid orthosis and air-cast braces.37 These prophylactic benefits were greatest for persons who had previously sustained ankle sprain injuries and those participating in high risk activities.37 A 2012 meta-analysis including 8 studies concluded that ankle taping or bracing do not significantly improve joint position sense or sense of movement threshold.38 The authors of the meta-analysis concluded that the mechanism for prophylactic effects of taping and bracing are likely due to restriction of joint range of motion, reduced mechanical instability, and improved confidence with functional tasks.38

Based upon the evidence reviewed, the full relationship between ankle injury and joint position sense remains unclear. The methodology used to measure joint position sense seems to capture different aspects of this sense and result in varying degrees of statistical significance. The results of most studies reviewed supports the presence of temporary deficits observed in passive ipsilateral measurements and movement threshold measurements of joint position sense in plantar flexion and inversion ranges during the acute stage following grade II and III sprains. Overtime, these changes in joint position sense appear to fade or become more difficult to detect through the same methodology. In many persons who go on to develop CAI, long term changes in position sense appear to be more easily detected through active position replication starting from a neutral position and moving into plantar flexion or inversion at a rate of less than 5˚/second.4 There is sufficient evidence to conclude that there is a relationship between changes in joint position sense and lateral inversion ankle sprain injury. It also appears that deficits in joint position sense play a role in CAI and recurrent ankle injuries. The results of the current literature do not allow for a comprehensive explanation based solely upon the altered reflexes within the feedback theory of articular de-afferentiation as presented by Freeman.18,21,23,36 There is reason to suspect along with signs of local and central adaptation at the spinal and supraspinal level as demonstrated in changes to contralateral limbs and motor control changes of more proximal joints seen in CAI.21,36 Interventions with proprioceptive training in a more general sense are recommended as part of rehabilitation, given evidence to support the efficacy towards improved function and injury prevention despite the lack of clear understanding of how they work. Modification of other intrinsic and extrinsic factors should also be addressed through rehabilitation with gradual progression towards return to high risk activities and environments. Supportive semi-rigid ankle bracing represents a relatively inexpensive approach which has demonstrated efficacy in the reduction of lateral inversion ankle sprains.

References

1. Waterman BR, Owens BD, Davey S, Zacchilli MA, Belmont PJ. The epidemiology of ankle sprains in the United States. *J Bone Joint Surg Am*. 2010;92(13):2279-2284. doi:10.2106/JBJS.I.01537.

2. Almeida SA, Williams KM, Shaffer RA, Brodine SK. Epidemiological patterns of musculoskeletal injuries and physical training. *Med Sci Sports Exerc*. 1999;31(8):1176-1182. http://www.ncbi.nlm.nih.gov/pubmed/10449021. Accessed November 23, 2015.

3. Fong DT-P, Hong Y, Chan L-K, Yung PS-H, Chan K-M. A systematic review on ankle injury and ankle sprain in sports. *Sports Med*. 2007;37(1):73-94. http://www.ncbi.nlm.nih.gov/pubmed/17190537. Accessed November 16, 2015.

4. McKeon JMM, McKeon PO. Evaluation of joint position recognition measurement variables associated with chronic ankle instability: A meta-analysis. *J Athl Train*. 2012;47(4):444-456. doi:10.4085/1062-6050-47.4.15.

5. Schiftan GS, Ross LA, Hahne AJ. The effectiveness of proprioceptive training in preventing ankle sprains in sporting populations: A systematic review and meta-analysis. *J Sci Med Sport*. 2015;18(3):238-244. doi:10.1016/j.jsams.2014.04.005.

6. Kannus P. Current Concepts Review Treatment of Acute Tears of the Lateral Ligaments of the Ankle. *J Bone Jt Surg*. 1991;73(2).

7. Ferran NA, Maffulli N. Epidemiology of sprains of the lateral ankle ligament complex. *Foot Ankle Clin*. 2006;11(3):659-662. doi:10.1016/j.fcl.2006.07.002.

8. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364-375.

9. Murphy DF, Connolly DAJ, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. *Br J Sports Med*. 2003;37(1):13-29. doi:10.1136/bjsm.37.1.13.

10. Beynnon BD, Murphy DF, Alosa DM. Predictive factors for lateral ankle sprains: A literature review. *J Athl Train*. 2002;37(4):376-380.

11. McCriskin BJ. Management and prevention of acute and chronic lateral ankle instability in athletic patient populations. *World J Orthop*. 2015;6(2):161. doi:10.5312/wjo.v6.i2.161.

12. Yeung MS, Chan KM, So CH, Yuan WY. An epidemiological survey on ankle sprain. *Br J Sports Med*. 1994;28(2):112-116. /pmc/articles/PMC1332043/?report=abstract. Accessed November 25, 2015.

13. Payne KA, Berg K, Latin RW. Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *J Athl Train*. 1997;32:221-225. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1320241/.

14. Willems TM, Witvrouw E, Delbaere K, Philippaerts R, De Bourdeaudhuij I, De Clercq D. Intrinsic risk factors for inversion ankle sprains in females - a prospective study. *Scand J Med Sci Sport*. 2005;15(5):336-345. doi:10.1111/j.1600-0838.2004.00428.x.

15. de Noronha M, Refshauge KM, Herbert RD, Kilbreath SL, Hertel J. Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? \* COMMENTARY. *Br J Sports Med*. 2006;40(10):824-828. doi:10.1136/bjsm.2006.029645.

16. Delahunt E. Neuromuscular contributions to functional instability of the ankle joint. *J Bodyw Mov Ther*. 2007;11(3):203-213. doi:10.1016/j.jbmt.2007.03.002.

17. Freeman M a, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br*. 1965;47(4):678-685.

18. Freeman M a, Wyke B. Articular reflexes at the ankle joint: an electromyographic study of normal and abnormal influences of ankle-joint mechanoreceptors upon reflex activity in the leg muscles. *Br J Surg*. 1967;54(12):990-1001.

19. Wu X, Song W, Zheng C, Zhou S, Bai S. Morphological study of mechanoreceptors in collateral ligaments of the ankle joint. *J Orthop Surg Res*. 2015;10:92. doi:10.1186/s13018-015-0215-7.

20. Freeman M a, Wyke B. The innervation of the knee joint. An anatomical and histological study in the cat. *J Anat*. 1967;101(Pt 3):505-532. doi:10.1159/000143037.

21. Hertel J. Sensorimotor Deficits with Ankle Sprains and Chronic Ankle Instability. *Clin Sports Med*. 2008;27(3):353-370. doi:10.1016/j.csm.2008.03.006.

22. van der Wal J. The architecture of the connective tissue in the musculoskeletal system-an often overlooked functional parameter as to proprioception in the locomotor apparatus. *Int J Ther Massage Bodywork*. 2009;2(4):9-23. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3091473&tool=pmcentrez&rendertype=abstract.

23. Ashton-Miller J a., Wojtys EM, Huston LJ, Fry-Welch D. Can proprioception really be improved by exercises? *Knee Surgery, Sport Traumatol Arthrosc*. 2001;9(3):128-136. doi:10.1007/s001670100208.

24. Glencross D, Thornton E. Position sense following joint injury. *J Sports Med Phys Fitness*. 1981;21(1):23-27. http://www.ncbi.nlm.nih.gov/pubmed/7278217. Accessed October 9, 2015.

25. Gross MT. Effects of recurrent lateral ankle sprains on active and passive judgments of joint position. *Phys Ther*. 1987;67(10):1505-1509. http://www.scopus.com/inward/record.url?eid=2-s2.0-0023640008&partnerID=40&md5=5341a56b9daa43fb748c582073452eed.

26. Garn SN, Newton R a. Kinesthetic awareness in subjects with multiple ankle sprains. *Phys Ther*. 1988;68(11):1667-1671.

27. Konradsen L, Olesen S, Hansen HM. Ankle sensorimotor control and eversion strength after acute ankle inversion injuries. *Am J Sports Med*. 1998;26(1):72-77.

28. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports*. 1999;9(2):104-109. doi:10.1111/j.1600-0838.1999.tb00217.x.

29. Refshauge KM, Raymond J, Kilbreath SL, Pengel L, Heijnen I. The effect of ankle taping on detection of inversion-eversion movements in participants with recurrent ankle sprain. *Am J Sports Med*. 2009;37(2):371-375. doi:10.1177/0363546508324309.

30. Delahunt E, Monaghan K, Caulfield B. Altered neuromuscular control and ankle joint kinematics during walking in subjects with functional instability of the ankle joint. *Am J Sports Med*. 2006;34(12):1970-1976. doi:10.1177/0363546506290989.

31. Monaghan K, Delahunt E, Caulfield B. Ankle function during gait in patients with chronic ankle instability compared to controls. *Clin Biomech (Bristol, Avon)*. 2006;21(2):168-174. doi:10.1016/j.clinbiomech.2005.09.004.

32. Delahunt E, Monaghan K, Caulfield B. Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the ankle joint during a single leg drop jump. *J Orthop Res*. 2006;24(10):1991-2000. doi:10.1002/jor.20235.

33. Drewes LK, McKeon PO, Paolini G, et al. Altered ankle kinematics and shank-rear-foot coupling in those with chronic ankle instability. *J Sport Rehabil*. 2009;18(3):375-388. http://www.ncbi.nlm.nih.gov/pubmed/19827501. Accessed December 3, 2015.

34. Lee AJY, Lin W-H. Twelve-week biomechanical ankle platform system training on postural stability and ankle proprioception in subjects with unilateral functional ankle instability. *Clin Biomech*. 2008;23(8):1065-1072. doi:10.1016/j.clinbiomech.2008.04.013.

35. Konradsen L, Magnusson P. Increased inversion angle replication error in functional ankle instability. *Knee Surg Sports Traumatol Arthrosc*. 2000;8(4):246-251. doi:10.1007/s001670000124.

36. Hung Y-J. Neuromuscular control and rehabilitation of the unstable ankle. *World J Orthop*. 2015;6(5):434-438. doi:10.5312/wjo.v6.i5.434.

37. Handoll, H. G. H., Rowe, B. R., Quinn, K. M., de Bie R. Interventions for preventing ankle ligament injuries (Review. *Cochrane Libr*. 2008;(3):22-50.

38. Raymond J, Nicholson LL, Hiller CE, Refshauge KM. The effect of ankle taping or bracing on proprioception in functional ankle instability: A systematic review and meta-analysis. *J Sci Med Sport*. 2012;15(5):386-392. doi:10.1016/j.jsams.2012.03.008.

39. Brown CN, Ross SE, Mynark R, Guskiewicz KM. Assessing Functional Ankle Instability with Joint Position Sense, Time to Stabilization, and Electromyography.pdf. *J Sport Rehabil*. 2004;13:122-134.

**Appendix A: Recommendations for Measurement of Joint Position Recognition deficits associated with CAI.**

“1. Compare JPR measures between groups with and without CAI.

2. During testing, the starting position of the foot should be between neutral and 308 of plantar flexion.

3. The active repositioning method is the most appropriate to use; however, passive repositioning has its benefits and can be explored further.

4. Early to midrange plantar flexion and the full range of inversion are the 2 directions that should be used. A combination of the 2 has not been explored, but we recommend investigating it systematically.

5. The repositioning velocity for testing should be less than 5˚/s. larger effects become more apparent as testing velocity decreases.

6. The most consistent data-reduction method for JPR testing is the calculation of the mean absolute error across at least 2”4

Taken from McKeon JMM, McKeon PO. Evaluation of joint position recognition measurement variables associated with chronic ankle instability: A meta-analysis. *J Athl Train*. 2012;47(4):444-456. doi:10.4085/1062-6050-47.4.15.