Exercise and Ankle Sprain Injuries: A Comprehensive Review

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Abstract: Ankle sprains are common in team sports and sports played on courts, and often result in structural and functional alterations that lead to a greater reinjury risk. Specific exercises are often used to promote neuromuscular improvements in the prevention and rehabilitation of ankle injuries. This literature review summarizes the neuromuscular characteristics of common ankle sprains and the effectiveness of exercise as an intervention for improving neuromuscular function and preventing reinjury. Our review found that appropriate exercise prescription can increase static and dynamic balance and decrease injury recurrence. In particular, the addition of dynamic activities in the exercise program can be beneficial because of the anticipatory postural adjustments identified as a key factor in the injury mechanism.

Keywords: ankle sprain; neuromuscular training; sensorimotor training; injury prevention; balance training

Introduction

The ankle is the second most commonly injured body part during sports,[1] with ankle sprains being the most common ankle injury.[1–3]

Chronic ankle injuries usually involve some type of long-term alteration in the proprioceptive and neuromuscular function.[4] Several researchers have demonstrated deficits of postural control in subjects sustaining an ankle sprain.[5–8] Also, deficits have been identified in the injured and uninjured leg, suggesting either the existence of bilateral deterioration or the increased likelihood of ankle sprains among athletes with poorer postural control.[5,8]

Despite the existence of several investigations, there is still controversy concerning the intrinsic risk factors that lead to ankle sprains[6,9] and the classification of functional ankle instability (FAI).[10] It is still necessary to define, classify, and clarify the factors leading to chronic ankle instability (CAI).[11] Moreover, there is little consensus in the terminology used to refer to preventive or rehabilitative training, and it is also necessary to define, classify, and clarify the factors leading to chronic ankle instability (CAI).[11] In addition, the optimal training methods to achieve these objectives remain unclear.

Thus, the aim of this review is to summarize the best evidence with regard to acute lateral ankle sprain, FAI, CAI, and the effectiveness of exercise in the prevention or rehabilitation of these injuries.

Methods

English-language articles on PubMed and the Cochrane Library were searched through October 2012. The search terms (in different combinations) were: *neuromuscular, sensorimotor, proprioceptive, balance, training, exercise, program, instability resistance training, postural control, perturbation, proprioception, coordination,*

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ankle sprain, and *injury prevention.* Although a systematic approach was not used, articles were reviewed by 2 of the authors to determine if they were appropriate for inclusion.

Neuromuscular Characteristics of Common Ankle Sprains

Acute Lateral Ankle Sprain and Residual Symptoms

An acute lateral ankle sprain can be defined as a traumatic injury of the ankle joint ligaments, resulting from an excessive inversion of the rear foot or a plantarflexion combined with adduction of the foot.[12]

Prospective studies found that impaired balance is associated with a greater risk of ankle injuries.[8,9,13,14] Other functional intrinsic deficits related to ankle injuries include lower eccentric eversion strength at slower isokinetic speeds, greater concentric strength in plantarflexion at higher isokinetic speed in relation to the dorsiflexion/plantarflexion ratio, and a lower inversion joint position sense in women.[14] Despite some authors stating that a reduced dorsiflexion range of motion[9,13] and a slower reaction time in the tibialis anterior and gastrocnemius muscles[9] are factors that increase ankle injury risk, a recent meta-analysis[14] suggested otherwise. Steffen and colleagues[15] found that the largest risk factor for ankle sprains is a prior sprain sustained during the previous year. This underscores the importance of prevention in the first place and proper rehabilitation after injury to avoid reinjury.

After experiencing an ankle sprain, it is common for patients to experience residual symptoms.[16,17] Recurrent sprains, "giving-way" episodes, pain, swelling, ankle instability, and decreased function are possible residual symptoms[12] that may occur in 74% of patients for 1.5 to 4 years after the injury.[16]

Recurrent Ankle Sprains

Recurrent sprains are defined as $>$ 2 sprains in the same ankle.[12] People who have experienced an ankle sprain are up to twice as likely to experience another within the following year.[18,19]

In a recent review, Hiller et al[20] analyzed the characteristics of persons experiencing recurrent sprains, finding that they often exhibit other deficits: increased postural sway while standing on 1 leg with their eyes closed, decreased foot clearance during gait, increased time to stabilization after performing a jump, and a lower concentric invertor strength. However, the cause–effect relationship between recurrent ankle sprains and postural stability is unknown. Interestingly, deficits in ankle range of motion, joint position sense, evertor strength, and peroneal latency were not found.

Functional Ankle Instability

Ankle instability can be mechanical or functional.[12] Mechanical instability refers to a movement that goes beyond its normal range,[3,12,20] and may be caused by mechanical deficiencies that alter the ankle joint mechanism, such as pathological laxity, decreased joint mobility, synovial inflammation, and degenerative changes.[21]

Although the definition of mechanical instability seems widely accepted, there is no universally accepted definition by which to classify functional instability.[10] Some authors define FAI as having recurrent sprains or "giving-way" episodes.[2,22,23] However, Delahunt et al[12] do not associate recurrent sprains with FAI, and they believe that functional instability entails frequent "giving-way" episodes and the feeling of instability in the ankle joint.

Different factors have been suggested as possible causes of the functional instability. Hertel[23] suggests that insufficiencies in proprioception, neuromuscular control, postural control, and strength are factors contributing to functional instability. Several authors have reported the presence of an altered postural control and sensorimotor deficits in people with FAI[6,7] in both static and dynamic tests.[7]

There is some controversy regarding evertor strength as a factor in FAI.[24] The results of a meta-analysis[24] suggest that concentric evertor weakness contributes to FAI, whereas other studies have reported that evertor strength deficits are not found in patients with recurrent sprains.[20] This discrepancy may be due to different definitions or to the fact that subjects without recurrent sprains but with symptoms of "giving way" or feelings of instability experience evertor strength deficits.[20]

In addition to muscular strength deficits, muscle activation patterns may be a factor in FAI. It has been suggested that an ankle sprain injury occurs in the initial contact of the foot with the ground[25]; thus, the majority of ankle injuries do not occur in a static position,[15,26] which suggests that dynamic muscle activation may be a factor in injury. Studies have shown that a sudden inversion injury occurs between 40 and 45 ms after foot contact.[27,28] A systematic review analyzed several studies that measured the activation of the peroneals and tibialis anterior in response to a postural disturbance in subjects with FAI and concluded that there was no evidence of delayed peroneal reaction times.[6] However, 1 study found a delayed tibialis anterior activation in subjects with FAI in response to a perturbation.[29]

Anderson and Behm[30] highlighted the important role of anticipatory postural adjustments in maintaining balance when performing tasks. Some authors have reported that patients with FAI have deficits in neuromuscular preparatory or anticipatory control ("feed-forward"), where the peroneus longus demonstrates reduced reaction time before the contact with the ground after performing jumps[31,32] or during walking.[33] Furthermore, Delahunt et al[31] found a statistically significant inverted position of the ankle joint accompanying the lower peroneal activation prior to contact with the ground. Differences in the reaction forces after performing a jump have also been observed, finding an earlier peak ground reaction force in FAI subjects than in healthy controls, which may increase the possibility of experiencing repeated injuries.[31,34] Moreover, subjects with FAI have been found to exhibit a decrease in vertical foot–floor clearance during the terminal swing phase of the gait cycle[33] and require more time to stabilize after a single-leg jump landing.[35]

Feed-forward deficits may increase injury risk because the ankle joint is less protected by an inadequate ankle joint position.[31] Furthermore, it has been argued that the preparatory activity is more important to maintain the dynamic stability and prevent injuries than reactive activity after foot contact with the ground, because of the short reaction time requirements in functional and dynamic tasks.[36] The importance of preparatory muscle activity for preventing injury during sports has been shown in a prospective study with female team handball and soccer players in relation to anterior cruciate ligament tears,[37] but remains poorly investigated for ankle sprains.

Chronic Ankle Instability

It has been established that CAI affects between 10% and 20% of people who have experienced an acute ankle sprain.[22] A diagnosis of CAI is considered when a patient experiences both types of instabilities (mechanical and functional) with residual symptoms for $\geq$ 1 year after the initial sprain.[12] This definition of CAI is based on the commonly accepted paradigm proposed by Hertel,[23] which distinguishes between functional and mechanical instability. However, controversy still exists regarding this classification and the terminology and factors that lead to these problems. Recently, Hiller et al[11] proposed an evolution of the paradigm developed by Hertel, where recurrent sprains are separate from the presence of both instability types. Thus, the new model consists of 7 subgroups, and "functional instability" is renamed as "perceived instability." This is because the authors found patients with both mechanical and functional instability but without recurrent sprains, and, conversely, some patients experience recurrent sprains but do not have any type of instability. This new approach may change future research, rehabilitation, and prevention, although further validation is required.

Hiller et al[20] reported that patients without recurrent sprains but with other CAI symptoms exhibit evertor strength deficits. Conversely, a review concluded that patients with CAI do not experience impaired evertor strength or activation deficits during a stimulus reaction, although lowered invertor muscle strength may be present.[38] Patients with CAI present with impaired ankle joint positional sense in the frontal plane and impaired dynamic postural control. This review highlights again the greater importance of the anticipatory adjustments for injury prevention. A recent study of patients with CAI found a lower co-contraction of the tibialis anterior and peroneus during the pre-landing after performing a jump, which may result in poor ankle stabilization and possibly increase the risk of injury.[39] However, the effects of training in the preparatory action require further investigation.[38]

Exercise for Ankle Injuries

One of the limiting factors in reviewing the literature on ankle exercise is the lack of consistent terminology. Although the term *proprioception training* is widely used, by definition it refers only to the afferent input,[40] whereas the exercises described in the literature primarily involve motor tasks.[41] Terms used in the literature to describe afferent and efferent aspects of ankle exercise are *neuromuscular training*,[4,42–48] *sensorimotor training*,[41,49] and *neuromotor training*.[50] Recently, an American College of Sports Medicine position stand[50] defined *neuromotor training* as a type of training that includes motor skills such as balance, coordination, agility, proprioception, and gait; however, the article used the term *neuromotor training* interchangeably with neuromuscular training.

Neuromuscular training programs incorporate different exercise components. For example, Paterno et al[48] include balance training, strengthening exercises, and plyometrics in their neuromuscular training program. More recently, Janssen et al[42] consider neuromuscular training to include sensorimotor exercises, proprioception, and balance training. O'Driscoll and Delahunt[46] consider neuromuscular exercise to include proprioception tasks, strength, or both; however, in a recent intervention by the same authors, their neuromuscular training program incorporated postural stability, strengthening exercises, plyometrics, and speed/agility.[43] Furthermore, Zech et al[4] consider neuromuscular and proprioceptive training to include balance exercises, plyometrics, and postural disturbances. Thus, a need exists for a consensus on the terminology used in the ankle rehabilitation literature,

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as this will facilitate the search for information and future research in this area. Based on the present literature review, we suggest using *neuromuscular training* as a general term for any type of training that involves neuromuscular stress in response to multiple tasks. However, a concise description of the exercise program is also essential.

Effectiveness of Exercise in Prevention and Rehabilitation

Several reviews and meta-analyses have examined the effects of neuromuscular training. It has been established that balance training is effective in improving postural and neuromuscular control in healthy and physically active participants,[45] as well as in prevention and rehabilitation.[40] Balance training may increase static and dynamic balance in athletes and nonathletes and may also have a positive effect on agility and jumping.[45] Wikstrom et al[5] also recommend balance and coordination exercises as a tool to improve postural control in patients with acute lateral ankle sprains. Moreover, neuromuscular training is effective in decreasing "giving-way" episodes after acute ankle sprains, increasing joint functionality and improving postural control.[4]

Anderson and Behm[30] recommended the combination of balance and strength training for people with somatosensory deficits. The application of instability resistance training using unstable devices is an interesting element to reach greater muscle activation with lower load, and a method to perform both strength training and balance training.[30,51] In fact, Behm and Anderson[52] stated that the main objective of performing training with unstable devices is to improve balance, stability, and proprioceptive capabilities. Furthermore, they highlight the role of the trunk/core stabilization as an essential element in maintaining both static and dynamic balance, especially when trying to exert forces on external objects. According to these authors, the integration of strength and balance training can improve motor control by increasing muscle activation, strength, and stiffness. Balance training provokes unexpected postural disturbances, eliciting a stabilization reflex through co-contraction mechanisms[30,52–55] with shorter reaction times.[55] The reflex activation of the muscles around the ankle contributes significantly to the joint stabilization.[41,55,56]

Some researchers have demonstrated the effectiveness of balance training to improve reaction time in the tibialis anterior muscle[57,58] and the peroneus longus[57] in subjects with a history of ankle sprains, and to improve synchronized activation of these muscles[2] in patients with CAI. Interestingly, Clark and Burden[57] note that it was unlikely that subjects have sufficient strength torque to prevent an ankle inversion injury; however, the authors suggest that balance training helps to reduce the risk of recurrent injuries by increasing joint stiffness. Other authors have agreed that improving reaction time does not prevent inversion ankle injuries, because it is improbable that peroneal reaction alone is enough to avoid injury.[6,10,26]

Decreasing the recurrence of ankle sprains is one of the most frequently demonstrated effects of exercise training in reviews that focus on exercise and ankle injuries. Van der Wees et al[59] published a review that analyzed the effectiveness of exercise therapy in patients with acute ankle sprains and FAI. The authors concluded that exercise (ie, proprioceptive training, coordination training, strength training, or functional exercises) is effective in the prevention of recurrent sprains for both types of patients. Similarly, Zech et al[4] confirm that proprioceptive/neuromuscular training could be effective in preventing recurrent sprains in patients with CAI or those experiencing an acute ankle sprain. Proprioception exercises, balance training, and strengthening improve postural control,[4,23] increase muscle strength, reduce muscle reaction time, and are effective for patients with recurrent "giving-way" episodes.[23] Verhagen and Bay[47] evaluated the effectiveness of different measures to prevent ankle sprains. After analyzing 24 studies, the authors noted that neuromuscular exercise is effective to prevent recurrent sprains, reducing them by approximately 50%. However, several authors have found no effect in the prevention of a first-time ankle sprain.[15,19,54,60,61]

Although the effectiveness of exercise in preventing recurrent ankle sprains has been demonstrated, the pathways through which exercise reduces risk remain unclear.[41] According to Hupperets et al,[41] sensorimotor training provides neurophysiological and morphological changes, such as increased strength or improved muscle reaction time, that lead to functional improvements, which in turn reduce the risk of recurrent sprains. Previously, Karlsson and Lansinger[62] found that neuromuscular training accelerates the healing process by restoring and strengthening the ligaments, muscles, and reflexes that protect the ankle. In addition, Taube et al[40] found that balance training adaptations occur in all sensory systems that facilitate postural control.

Balance training is also used to improve postural control of patients with CAI.[5,38] Webster and Gribble[63] conducted a systematic review to test the effectiveness of neuromuscular rehabilitation in patients with CAI. The authors confirmed the effectiveness of functional closed-kinetic chain exercises, especially in subjects using unstable devices such as a wobble board to improve dynamic postural control and self-reported outcomes, including reductions in recurrent injuries. de Vries

Table 1. Effects of Neuromuscular/Neuromotor/Sensorimotor Training in Ankle Sprain Injuries

Diagnosis	Neuromuscular/Neuromotor/ Sensorimotor Training (Balance, Proprioception, Plyometrics, Strength, Speed/Agility)
Acute ankle sprain	Improve postural control[4,5]
	Decrease "giving-way" episodes[4]
	Decrease recurrent ankle sprains[4,47,59]
Functional ankle instability	Improve postural control[4,22]
	Decrease "giving-way" episodes[22]
	Decrease recurrent ankle sprains[4,22,47,59]
	Increase muscle strength[22]
	Improve muscle reaction time[22]
Chronic ankle instability	Improve postural control[4,5,38,46,63]
	Decrease recurrent ankle sprains[46,47,63]
	Improve joint position test[46]
	Improve muscle reaction time[46]
	Improve shank–rear-foot coupling[46]

and colleagues[22] analyzed other CAI reviews and concluded that neuromuscular training is effective in the treatment of subjects with this injury. O'Driscoll and Delahunt[46] recently conducted a systematic review of neuromuscular training (proprioception, strength, or both) in patients with CAI. Their review found moderate evidence of neuromuscular training effects on static and dynamic balance, joint position sense, isometric strength, muscle onset latencies, injury recurrence, and shank–rear-foot coupling. Table 1 summarizes the most demonstrated benefits of exercise on ankle sprain injuries.

Conclusion

Neuromuscular/neuromotor/sensorimotor training improves postural control, increases static and dynamic balance, and decreases injury recurrence in subjects with acute ankle sprains, FAI, and CAI. This type of intervention reduces "giving-way" episodes in patients after an acute ankle sprain and in patients with FAI. Muscle strength and muscle reaction time are improved in FAI and CAI patients with training. Furthermore, improvements in joint position sense and shank–rear-foot coupling have been shown in CAI subjects.

Some of the conflicting findings are probably due to differences in training protocols such as volume, intensity, and exercises; therefore, more investigations that address training variables and periodization are needed. Evidence suggests that exercises to promote feed-forward or anticipatory postural adjustments, such as agility, plyometrics, landings, and other kinds of dynamic tasks, must be included in training programs due to their relevance to ankle injury prevention, daily activities, and in improving anticipatory postural deficits.

Conflict of Interest Statement

Joaquin Calatayud, MSc, Sebastien Borreani, MSc, Juan Carlos Colado, PhD, Jorge Flandez, MSc, Phil Page, PhD, and Lars L. Andersen, PhD, have no conflicts of interest to declare.

References

1. 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.
2. Eils E, Rosenbaum D. A multi-station proprioceptive exercise program in patients with ankle instability. *Med Sci Sports Exerc*. 2001;33(12):1991–1998.
3. Hertel J. Functional instability following lateral ankle sprain. *Sports Med*. 2000;29(5):361–371.
4. Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Neuromuscular training for rehabilitation of sports injuries: a systematic review. *Med Sci Sports Exer*. 2009;41(10):1831–1841.
5. Wikstrom EA, Naik S, Lodha N, Cauraugh JH. Balance capabilities after lateral ankle trauma and intervention: a meta-analysis. *Med Sci Sports Exerc*. 2009;41(6):1287–1295.
6. Munn J, Sullivan SJ, Schneiders AG. Evidence of sensorimotor deficits in functional ankle instability. *J Sci Med Sport*. 2010;13(1):2–12.
7. Arnold BL, De la Motte S, Linens S, Ross SE. Ankle instability is associated with balance impairments: a meta-analysis. *Med Sci Sports Exerc*. 2009;41(5):1048–1062.
8. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability. Part 1: Can deficits be detected with instrumented testing? *J Athl Train*. 2008;43(3):293–304.
9. Willems TE, Witvrouw E, Delbaere K, Mahieu N, De Bourdeaudhuij I, De Clercq D. Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. *Am J Sports Med*. 2005;33(3):415–423.
10. Delahunt E. Peroneal reflex contribution to the development of functional instability of the ankle joint. *Phys Ther Sport*. 2007;8(2):98–104.
11. Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: evolution of the model. *J Athl Train*. 2011;46(2):133–141.
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. 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? *Br J Sports Med*. 2006;40(10):824–828.
14. Witchalls J, Blanch P, Waddington G, Adams R. Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. *Br J Sports Med*. 2012;46(7):515–523.
15. Steffen K, Andersen TE, Krosshaug T, et al. ECSS Position Statement 2009: prevention of acute sports injuries. *Eur J Sport Sci*. 2010;10(4):223–236.
16. Anandacoomarasamy A, Barnsley L. Long term outcomes of inversion ankle injuries. *Br J Sports Med*. 2005;39(3):14.
17. 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.
18. Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scand J Med Sci Sports*. 1997;7(3):166–171.
19. Verhagen E, Van der Beek A, Twisk J, Bouter L, Bahr R, Van Mechelen W. The effect of a proprioceptive balance board training program for the prevention of ankle sprains. *Am J Sports Med*. 2004;32(6):1385–1393.
20. Hiller CE, Nightingale EJ, Christine Lin CW, Coughlan GF, Caulfield B, Delahunt E. Characteristics of people with recurrent ankle sprains: a systematic review with meta-analysis. *Br J Sports Med*. 2011;45(8):660–672.

21. de Vries J, Krips R, Sierevelt I, Blankevoort L, van Dijk C. Interventions for treating chronic ankle instability. *Cochrane Database Syst Rev*. 2011;(8):CD004124.
22. Loudon JK, Santos MJ, Franks L, Liu W. The effectiveness of active exercise as an intervention for functional ankle instability: a systematic review. *Sports Med*. 2008;38(7):553–563.
23. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364–375.
24. 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.
25. Wright IC, Neptune RR, van den Bogert AJ, Nigg BM. The influence of foot positioning on ankle sprains. *J Biomech*. 2000;33(5):513–519.
26. Gutierrez GM, Kaminski TW, Douex AT. Neuromuscular control and ankle instability. *PM R*. 2009;1(4):359–365.
27. Ashton-Miller JA, Ottaviani RA, Hutchinson C, Wojtys DM. What best protects the inverted weightbearing ankle against further inversions? Evertor muscle strength compares favorably with shoe height, athletic tape, and three orthoses. *Am J Sports Med*. 1996;24(6):800–809.
28. Gruneberg C, Nieuwenhuijzen PHJA, Duysens J. Reflex responses in the lower leg following landing impact on an inverting and non-inverting platform. *J Physiol*. 2003;550(Pt 3):985–993.
29. Lofvenberg R, Karrholm J, Sundelin G, Ahlgren O. Prolonged reaction time in patients with chronic lateral instability of the ankle. *Am J Sports Med*. 1995;23(4):414–417.
30. Anderson K, Behm D. The impact of instability resistance training on balance and stability. *Sports Med*. 2005;35(1):43–53.
31. 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.
32. Caulfield B, Crammond T, O'Sullivan A, Reynolds S, Ward T. Altered ankle-muscle activation during jump landings in participants with functional instability of the ankle joint. *J Sport Rehabil*. 2004; 13(3):189–200.
33. 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.
34. Caulfield B, Garrett M. Changes in ground reaction force during jump landing in subjects with functional instability of the ankle joint. *Clin Biomech*. 2004;19(6):617–621.
35. Ross SE, Guskiewicz KM, Yu B. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. *J Athl Train*. 2005;40(4):298–304.
36. Wikstrom EA, Tillman MD, Chmielewski TL, Borsa PA. Measurement and evaluation of dynamic joint stability of the knee and ankle after injury. *Sports Med*. 2006;36(5):393–410.
37. Zebis MK, Andersen LL, Bencke J, Kjaer M, Aagaard, P. Identification of athletes at future risk of anterior cruciate ligament ruptures by neuromuscular screening. *Am J Sports Med*. 2009;37(10):1967–1973.
38. Holmes A, Delahunt E. Treatment of common deficits associated with chronic ankle instability. *Sports Med*. 2009;39(3):207–224.
39. Cheng-Feng L, Chin-Yang C, Chia-Wei L. Dynamic ankle control in athletes with ankle instability during sports maneuvers. *Am J Sports Med*. 2011;39(9):2007–2015.
40. Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiol*. 2008;193(2):101–116.
41. Hupperets MDW, Verhagen EALM, van Mechelen W. Effect of sensorimotor training on morphological, neurophysiological, and functional characteristics of the ankle: a critical review. *Sports Med*. 2009;39(7):591–605.
42. Janssen KW, van Mechelen W, Verhagen E. Ankles back in randomized controlled trial (ABrCt): braces versus neuromuscular exercises for the secondary prevention of ankle sprains. Design of a randomised controlled trial. *BMC Musculoskelet Disord*. 2011;12:210.
43. O'Driscoll J, Kevin F, Delahunt E. Effect of a 6-week dynamic neuromuscular training programme on ankle joint function: a case report. *Sports Med Arthrosc Rehabil Ther Technol*. 2011;3:13.
44. Zemková E, Hamar D. The effect of 6-week combined agility-balance training on neuromuscular performance in basketball players. *J Sports Med Phys Fitness*. 2010;50(3):62–67.
45. Zech A, Hübscher M, Vogt L, Banzer W, Hänsel F, Pfeifer K. Balance training for neuromuscular control and performance enhancement: a systematic review. *J Athl Train*. 2010;45(4):392–403.
46. O'Driscoll J, Delahunt E. Neuromuscular training to enhance sensorimotor and functional deficits in subjects with chronic ankle instability: a systematic review and best evidence synthesis. *Sports Med Arthrosc Rehabil Ther Technol*. 2011;3:19.
47. Verhagen EALM, Bay K. Optimising ankle sprain prevention: a critical review and practical appraisal of the literature. *Br J Sports Med*. 2010; 44(15):1082–1088.
48. Paterno MV, Myer GD, Ford KR, Hewet TE. Neuromuscular training improves single-limb stability in young female athletes. *J Orthop Sports Phys Ther*. 2004;34(6):305–316.
49. Gruber M, Gollhofer A. Impact of sensorimotor training on the rate of force development and neural activation. *Eur J Appl Physiol*. 2004;92(1):98–105.
50. Garber CE, Blissmer B, Deschenes MR, et al; American College of Sports Medicine. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334–1359.
51. Behm DG, Colado JC. The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. *Int J Sports Phys Ther*. 2012;7(2):226–241.
52. Behm DG, Anderson KG. The role of instability with resistance training. *J Strength Cond Res*. 2006;20(3):716–722.
53. Ferreira LA, Pereira WM, Rossi LP, Kerpers II, de Paula Jr AR, Oliveira CS. Analysis of electromyographic activity of ankle muscles on stable and unstable surfaces with eyes open and closed. *J Bodyw Mov Ther*. 2011;15(4):496–501.
54. Hrysomallis C. Relationship between balance ability, training and sports injury risk. *Sports Med*. 2007;37(6):547–556.
55. Behm DG, Drinkwater EJ, Willardson JM, Cowley PM; Canadian Society for Exercise Physiology. Canadian Society for Exercise Physiology position stand: the use of instability to train the core in athletic and nonathletic conditioning. *Appl Physiol Nutr Metab*. 2010;35(1):109–112.
56. Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train*. 2002; 37(1):71–79.
57. Clark VM, Burden AM. A 4-week wobble board exercise programme improved muscle onset latency and perceived stability in individuals with a functionally unstable ankle. *Phys Ther Sport*. 2005;6(4):181–187.
58. Osborne MD, Chou L, Laskowski E, Smith J, Kaufman KR. The effect of ankle disk training on muscle reaction time in subjects with a history of ankle sprain. *Am J Sports Med*. 2001;29(5):627–632.
59. van der Wees PJ, Lenssen AF, Hendriks EJ, Stomp DJ, Dekker J, de Bie RA. Effectiveness of exercise therapy and manual mobilisation in ankle sprain and functional instability: a systematic review. *Aust J Physiother*. 2006;52(1):27–37.
60. Hupperets MDW, Verhagen EALM, van Mechelen W. Effect of unsupervised home based proprioceptive training on recurrences of ankle sprain: randomized controlled trial. *BMJ*. 2009;339:b2684.
61. Mohammadi F. Comparison of 3 preventive methods to reduce the recurrence of ankle inversion sprains in male soccer players. *Am J Sports Med*. 2007;35(6):922–926.
62. Karlsson J, Lansinger O. Chronic lateral instability of the ankle in athletes. *Sports Med*. 1993;16(5):355–365.
63. Webster KA, Gribble PA. Functional rehabilitation interventions for chronic ankle instability: a systematic review. *J Sport Rehabil*. 2010;19(1):98–114.