Restricted ankle dorsiflexion: methods to assess and improve joint function

By Louis Howe, MSc, BSc (Hons), ASCC

OVERVIEW

The presentation of compensatory movement strategies during a high load environment has been suggested as a potential risk factor for numerous lower extremity injuries. Deficiencies in ankle dorsiflexion range of motion may restrict movement pathways, potentially causing proximal compensation and, in turn, excessive stress to active and passive tissues. This article will discuss evidence surrounding the influence of a hypomobile ankle joint on lower extremity function, as well as methods to assess and improve ankle mechanics and subsequent movement patterns.

Introduction

During high load sporting situations, excessive motion at the hip joint in the frontal and transverse plane may compromise the integrity of various structures within the lower extremity.[15,21,27,55,61] The ability of the neuromuscular system to prevent these motions from occurring is crucial in avoiding injury. When compensatory movement strategies (CMS) within the lower extremity are present, changes in normal hip muscle recruitment patterns have been observed. Reductions in gluteal muscle strength,[32] activation[11,25,31,56,72] and delayed onset of activation[10] are all associated with poor dynamic alignment during functional activities. This occurrence has led to localised exercise-based interventions being suggested in order to correct dysfunctions.[57]

However, recent research indicates that CMS may not be exclusively attributed to local motor control deficiencies. Fundamentally, reduced function within stabilising muscles around the hip may be caused by an underlying deficiency in mobility elsewhere in the lower extremity. Limited ankle dorsiflexion range of motion (ROM) has been shown to impede normal movement pathways, therefore necessitating various CMS to allow for the completion of functional activities.[41,43,53]

It is, therefore, the aim of this article to describe ankle function, and the influences it possess on knee and hip mechanics. This discussion will provide coaches with an understanding for the synergistic relationship between the ankle and proximal joint segments. Tools for assessing ankle dorsiflexion ROM will be discussed. Finally, the CMS derived from ankle hypomobility will be presented, alongside methods to enhance lower extremity function.

AUTHOR'S BIO



LOUIS HOWE, BSC, ASCC

Louis has been coaching elite level athletes for over seven years, previously working for one of London's top universities. He is currently a lecturer in strength and conditioning at St Mary's University, London, teaching on the undergraduate programme. Alongside this role, Louis provides strength and conditioning services to a group of international track and field athletes. Academically, Louis recently completed his MSc in sports rehabilitation.

'This evidence highlights the soleus muscle as the primary limiting factor to ankle dorsiflexion ROM during movement patterns involving knee flexion'

Compensatory movement strategies

Locally, a lack of ankle dorsiflexion ROM presents as a risk factor for common sports injuries such as achilles tendinopathy, ankle sprains, and tibial stress fractures.[54] Research also indicates an association with proximal injuries such as hamstring strains,[17] patella tendinopathy,[2] anterior knee pain[45] and anterior cruciate ligament injury.[70] Although the exact relationship between a loss of ankle dorsiflexion ROM and injury occurrence is unclear, theoretical models have been proposed based on the development of CMS caused by ankle hypomobility.

During normal weight-bearing activities, pronation of the lower extremity is required for the dissipation of forces during closed chain movements. Calcaneal eversion initiates pronation, causing the talus to plantar flex and adduct.[63,65,66] As a consequence, the tibia and subsequently the femur are guided into internal rotation,[63] encouraging gluteal activation.[56] This tri-planar kinematic sequence is functionally essential in order to load the neuromuscular system in preparation for propulsion.

When an athlete lacks sufficient ankle dorsiflexion, excessive pronation of the foot complex may be necessary in order to compensate. This strategy causes a reduced structural congruency of the talonavicular and calcaneocuboid joints (composing the midtarsal joint), facilitating compensatory dorsiflexion at the midfoot and permitting the tibia to continue its forward trajectory.[63,65,66] This is visually demonstrated as a collapse of the medial longitudinal arch. A strong contraction of the gluteals in this instance would be inhibited to allow for the femur and consequently the tibia to internally rotate, encouraging the knee joint to displace medially relative to the fixed foot. This CMS permits sagittal plane motion to take place around the oblique axis of the midtarsal joint.[64] Research has supported this theoretical model in subjects with ankle dorsiflexion restriction, demonstrating increased knee valgus angles secondary to poor proximal control.[43,53]

Where a pronation strategy is not adopted, athletes who lack ankle dorsiflexion will not be able to achieve acceptable knee flexion angles during closed chain activities. If the constraints of the movement task allow, this may cause an increased hinge at the hip joint producing a forward lean of the trunk. When performing movements in a high load environment, the spine will be compelled to withstand excessive lumbar forces.[60] During a landing task, the same CMS may present as an aggressive jarring strategy with reduced knee flexion angles during force acceptance.[16] In this instance, the knee joint will display a quadriceps dominant CMS, associated with anterior cruciate ligament injury.[27]

Potential limitations to ankle dorsiflexion

During level-ground gait, 10-20° of ankle dorsiflexion is a prerequisite for ideal mechanics within the lower extremity.[51] This requirement increases during running, with up to 30° being desirable.[51] During full ROM squatting, normative data for ankle dorsiflexion has not yet been established.[38] However, Hemmerich et al[27] found dorsiflexion angles of 39 ± 6° were required to maintain the foot complex against a flat surface. It is therefore likely that many athletes must possess approximately 40° of ankle dorsiflexion ROM during weight-bearing tasks in order to optimally complete the necessary movement patterns of their sport.

Muscles located posteriorly to the talocrural joint axis of rotation act either as a primary or secondary plantar flexor.[50] Therefore, reduced extensibility of the gastrocnemius and soleus complex may present as the main culprit in preventing ankle dorsiflexion ROM.[22] However, the gastrocnemius and soleus muscles differ in their articular characterisation. As such, the biarticular gastrocnemius muscle is a knee flexor and ankle plantar flexor.[50] During activities demanding concomitant ankle dorsiflexion and knee flexion (ie, squatting), the gastrocnemius insertion is elongated distally while the origin is shortened proximally. This scenario leads to limited change in length,[60] rendering the gastrocnemius incapable of limiting ankle dorsiflexion ROM during movements requiring simultaneous knee flexion. This evidence highlights the soleus muscle as the primary limiting factor to ankle dorsiflexion ROM during movement patterns involving knee flexion.

Limited ankle dorsiflexion may also result from a lack of arthrokinematic motion at the talocrural joint.[13] For the ankle joint to dorsiflex, the talus must glide in a posterior direction relative to the mortise to avoid impinging anteriorly.[39] Posterior glide of the talus has been shown to be limited in individuals with an anterior positional fault of the talus, secondary to a history of injury at the ankle joint.[70] This positional fault is produced





Figure 1. (left image) The weight-bearing lunge test. Athletes stand facing a bare wall, with the tested foot positioned closest to the wall. The second toe, centre of the calcaneus and centre of the patella are all aligned perpendicular to the wall and remain within this plane throughout the test. The subject places their non-testing leg behind them so as not to obscure results, with the hands located on the wall ahead. The athlete lunges forward until the front knee contacts the wall. The heel must remain in contact with the floor throughout. Upon successful completion, athletes are repositioned 1cm further away from the wall. A measurement is taken from the greater toe to the wall from the last successful effort

Figure 1. (right image) The modified weight-bearing lunge test. The modified WBLT is performed using the same setup as the WBLT. However, for gastrocnemius extensibility to be measured, the modified WBLT uses the back leg for assessment. The athlete assumes the lunge position, with the front foot against the wall so as to prevent obscuring results. It is recommended that to start, the testing leg is placed one foot and a half length away from the wall. The testing leg is positioned so that the heel makes contact with the ground, and the knee is extended. The athlete then attempts to lunge forward until the front knee makes contact with the wall. Upon successful completion, the athlete repositions the back leg 1cm further away from the wall. This is continued until they can no longer attain a touch with the knee of the front leg. From the last successful effort a measurement is taken from the greater toe of the back leg, to the wall

by the excessive anteriorly capsular laxity caused by the plantar flexion mechanism associated with a lateral ankle ligament injury.[49] Although much of the research identifying altered ankle arthrokinematics has used previously injured athletes, joint mobilisations have been suggested for any individual demonstrating a hypomobile ankle joint.[39] As such, interventions aimed at improving accessory ankle joint motion in asymptomatic populations have shown immediate increases in ankle dorsiflexion ROM.[23,67]

Methods to assess ankle dorsiflexion range of motion

When assessing ankle dorsiflexion ROM in an isolated fashion, both weight-bearing[4] and non-weight-bearing[62] techniques are available to coaches. However, Whitting et al[69] established a poor correlation between weight-bearing and non-weight-bearing tests (r^2=0.18), with non-weight-bearing tests underestimating functional capacity. The authors suggest the two assessments may describe separate aspects of ankle dorsiflexion mobility; non-weight-bearing tests representing passive stiffness and weight-bearing tests indicating contractile and non-contractile tissue extensibility.[69] Therefore, when correlating ankle dorsiflexion ROM with functional activities involving active stabilising strategies, a weight-bearing test is recommended over its passive equivalent.[69]

One method that has been suggested is the weight-bearing lunge test (WBLT) (Figure 1).[4,27,34,37,52] When investigating the WBLT, Bennell et al[4] reported a standard error of measurement of 0.4 centimetres (cm), with a strong inter-tester and intersession reliability, and intra-class correlation coefficients of 0.97-0.99. Relationships have been established between ankle dorsiflexion ROM during the WBLT, and the performance of both a unilateral[29] and bilateral[14] squat variation, demonstrating its practical relevance. Due to anthropometric differences it is unlikely that a gold standard exists; however, scores of 9.5–14 cm have been recorded in healthy individuals.[4,28,37]

As previously discussed, with movement tasks demanding a flexed knee it is unlikely that the biarticular gastrocnemius muscle provides a limitation to ankle dorsiflexion ROM. As such, gastrocnemius extensibility is not measured during the WBLT. A modified version of the WBLT may accurately assess the gastrocnemius' contribution to restricted ankle dorsiflexion ROM, if deemed necessary (see Figure 2). To the author's knowledge, this assessment has not been validated within the literature, and

therefore is proposed only from a theoretical basis. It should be noted, if looking to identify limited ankle dorsiflexion as cause for the CMS previously discussed in this article, the modified WBLT may be inappropriate and therefore coaches should employ the WBLT.

The preferred movement strategy during functional tasks should also be considered by coaches conducting screens. It is possible that in an isolated assessment such as the WBLT, sufficient ankle dorsiflexion may be present. Yet during integrated movement patterns (ie, squatting variations), this ROM may not be used as the primary strategy. Athletes may instead choose to initiate movement with a CMS, such as the pronation strategy previously discussed, in order to gain added stability via overactive global mobilisers and passive structures. In this case, a mobility intervention would not prove successful. Instead, exercises that provide a neuromuscular education process may achieve a more desirable outcome as the athlete learns to control ankle dorsiflexion motion whilst minimising CMS.

In order to make this distinction, a dynamic assessment that requires full ankle dorsiflexion should be employed. By including tests such as the Star Excursion Balance Test (SEBT) with an anterior reach,[29] CMS may be identified in athletes possessing limited ankle dorsiflexion ROM. In theory, the distance the knee can travel over the greater toe during the WBLT should be replicated during the SEBT with an anterior reach. By employing both a WBLT, providing four points of stability, and the SEBT, offering just one point of stability, coaches can distinguish between a true restriction within the ankle complex and the inability to control the available ROM during single-leg activities.

Lastly, as motor control strategies for low and high load situations are modulated by separate higher processes within the central nervous system,[30] it is suggested that both low and high load assessments be incorporated.[47] This may allow for coaches to identify stabilisation discrepancies in either environment, leading to more effective programme design. If only low load assessments are used (ie, SEBT with an anterior reach), coaches will not gain an appreciation of how an athlete chooses to cope during a high load environment (ie, landing from a hop) on the restricted leg. Without the identification of high load CMS, the re-training process may prove unsuccessful for many athletes.

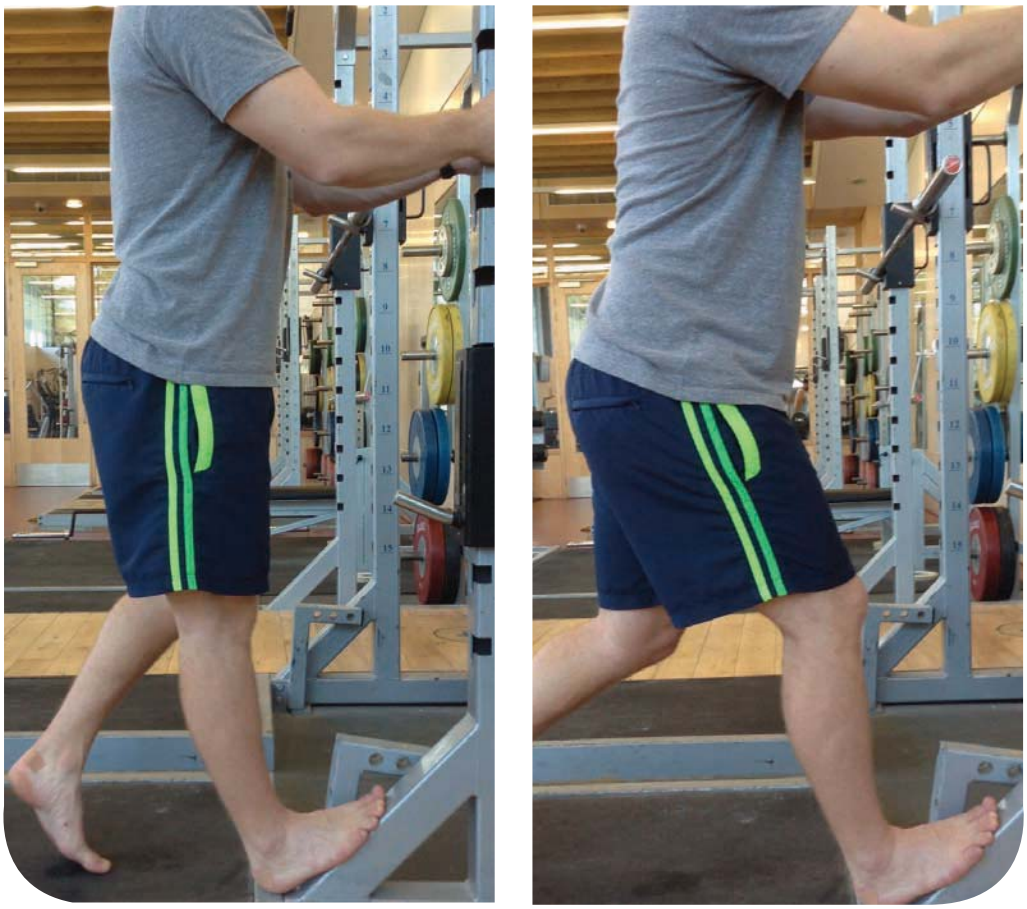


Figure 3. Example of static stretch position for gastrocnemius (left image) and soleus (right image) muscles

Methods to increase ankle dorsiflexion range of motion

Once a thorough assessment has been completed and the tissue responsible for causing the restriction has been identified, coaches must select the appropriate tool in order to correct the deficiency. If myofascial restrictions are detected on assessment, techniques such as proprioceptive neuromuscular facilitation[59] and static stretching[18,19,33,58,71] have all shown positive results in increasing ankle dorsiflexion ROM. Depending on the findings within the assessment, either a straight or bent-knee position may be used in order to target the gastrocnemius or soleus respectively (Figure 3).

Similarly, self-massage may also be employed to increase ankle dorsiflexion ROM. Using the technique demonstrated in Figure 4, Halperin et al[24] identified similar gains in ankle dorsiflexion ROM when compared to a static stretching intervention. Interestingly, differences were found in the force production capacity of the plantar flexors, with only static stretching demonstrating short-term reductions in force development.[24] These results indicate that if acute increases in ankle dorsiflexion are targeted prior to training or competition, self-massage is a more attractive modality to prevent compromising performance qualities.

For subjects who lack the vital posterior glide of the talus during ankle dorsiflexion, mobilisation techniques suggested by Mulligan[48] have been shown to correct pathomechanics, leading to immediate increases in ankle dorsiflexion ROM.[5] Although much of the literature on mobilisations has used injured athletes,[5,12,20] Vicenzino et al[67] and Guo et al[23] both demonstrated statistically significant increases in ankle dorsiflexion ROM in healthy subjects. Changes following mobilisations aimed at improving the athrokinematics of the joint may go beyond correcting positional faults. Maitland[42] suggests modifications in sensorimotor function may also occur, with stimulation of mechanoreceptors located in the joint capsule and ligamentous tissue. This excitation is proposed to increase afferent information being transmitted to the medulla leading to central adaptations.[42] Köhne et al[36] supported this suggestion, establishing enhanced proprioception following mobilisations.

Although hands-on manual therapy techniques are beyond the practice of the S&C coach, self-mobilisations when prescribed appropriately have been recommended.[9] Mobilisations are classified by grades I to IV depending on their treatment movements (Table 1). Cosby and Grindstaff[9] suggest self-mobilisations be completed to an equivalent grade III or IV mobilisation.



Figure 4. Example of self-massage technique for the gastroc-soleus complex. Athletes assume a seated position on a chair, with one knee flexed to 90° and the ankle slightly plantar flexed using a heel support. Flexing forward, the athlete massages the myofascial tissue using a roller massager. Halperin et al[24] showed positive results using a cadence of one second to roll the length of the calf, for 30 seconds for three sets. Intensity was maintained at 7/10 using the rate of perceived pain[24]

Recently, prescribing joint self-mobilisation has grown in popularity within the strength and conditioning community. Coaches should note that not all individuals are candidates for joint mobilisation. Table 2 (on next page) provides an exclusion criterion. It is imperative that coaches are fully aware of their athlete's circumstances before advocating joint self-mobilisations. The authors of this article recommend that all athletes should be screened by a medical practitioner prior to joint mobilisation prescription.

In some cases, self-mobilisations may prove ineffective for athletes with myofascial restrictions limiting ankle dorsiflexion. Myofascial and articular restrictions may be differentiated by the sensations an athlete experiences during the WBLT.[22] If tightness is felt along the posterior surface of the lower

Table 1: Classification system for mobilisations techniques[1]

GRADE	DESCRIPTION
I	Small-amplitude performed at the beginning of the ROM
II	Large-amplitude performed within the mid-ROM
III	Large-amplitude performed up to the limit of the ROM
IV	Small-amplitude performed at the very end of the ROM

Table 2: Exclusion criteria. Individuals who possess any of the following characteristics or pathologies should not be prescribed self-mobilisations[1]

EXCLUSION CRITERIA
Acute inflammation
Osteoporosis
Advanced osteoarthritis
Infections
Premature stressing of surgical structures
Congenital bone deformities
Malignancy
Rheumatoid arthritis
Confirmed or suspected bone fractures
Neurological or vascular signs

leg, it is likely that the soleus complex is the culprit. Conversely if the athlete describes a pinching at the anterior aspect of the talocrural joint associated with an anterior impingement, then self-mobilisations are indicated.[22]

Figure 5 demonstrates a number of self-mobilisations to improve the arthrokinematics of the ankle joint. It is likely that an athlete's response will vary depending on each mobilisation, and therefore it is recommended that an athlete practise numerous techniques in order to determine which one achieves the best results. As with all techniques aimed at improving joint mobility, it is important to record quantitative changes. Strength and conditioning coaches should be sure to test pre and post-intervention. This will help determine which method achieves the greatest increase in ankle dorsiflexion ROM.

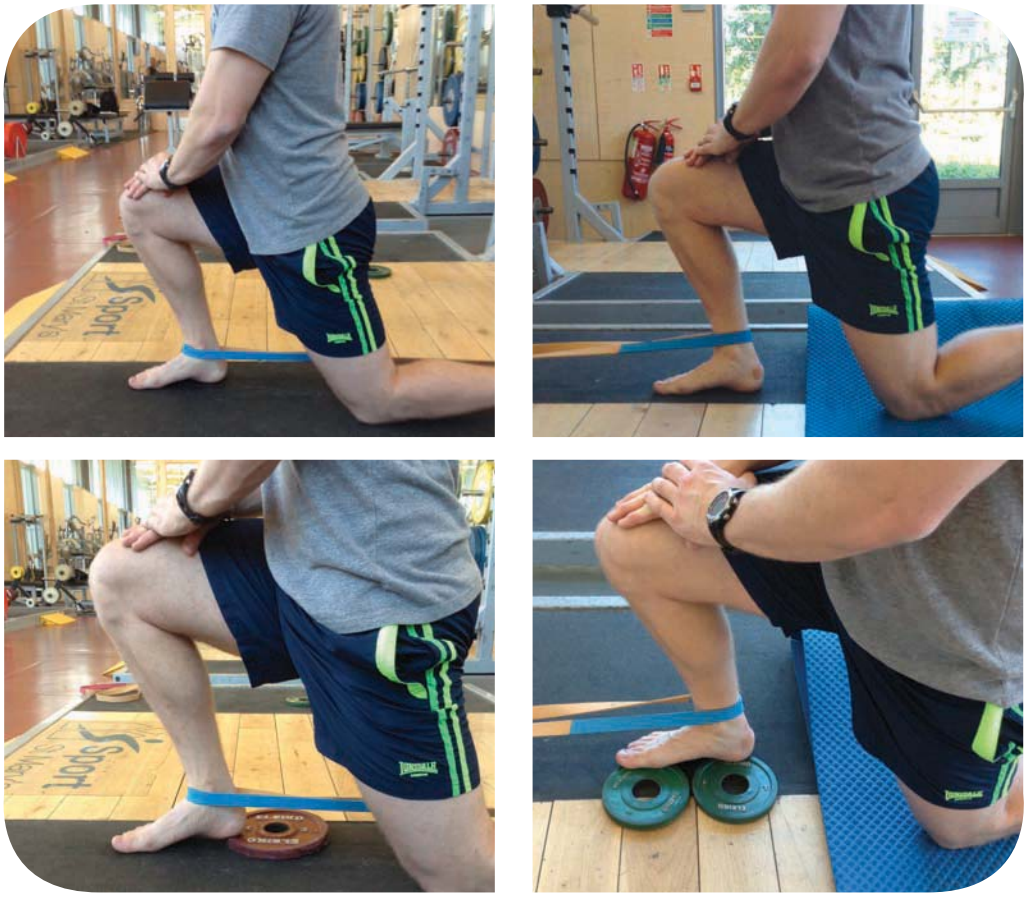


Figure 5. Examples of self-mobilisations aimed at improving ankle dorsiflexion ROM. Athletes should assume a similar setup to the WBLT, using support where necessary to maximise stability. Two techniques may be employed in order to facilitate posterior glide of the talus relative to the ankle mortise. Both techniques require either a band, or a strap secured against a fixed pole. Firstly, with a band positioned over the anterior aspect of the ankle joint, an anteroposterior glide can be achieved on the talus relative to the distal tibia and fibula (top left). This mobilisation can be enhanced by slightly elevating the heel, preventing the band from slipping superiorly off of the talus (bottom left). Alternatively, with a band placed around the posterior surface of the distal leg, a posteroanterior glide to the tibia and fibula assists the tibia and fibula to move anteriorly on a fixed talus (top right). In order to prevent compensatory dorsiflexion from the midtarsal joints, the calcaneus can be inverted by slightly elevating the medial aspect of the heel and the first metatarsal (bottom right). With either technique, athletes are suggested to move in and out of end range using the equivalent of either a grade III or IV mobilisation, remaining pain-free throughout.[9] Cosby et al[9] recommends 2–3 sets of 30–60 seconds using slow oscillations.

Reducing compensatory movement strategies

It is beyond the scope of this article to present all principles that provide the foundation for designing and implementing a neuromuscular re-education programme leading to the reduction in CMS. However, in this section certain components of a neuromuscular re-education programme will be highlighted. For further information, readers are referred to texts by Comerford and Mottram,[7] Cook et al,[8] and McGill.[43]

Until ankle mobility has been achieved, CMS identified during a screening process are likely to remain. Any CMS driven from a loss of ankle dorsiflexion is in actuality a functional response, allowing for the completion of athletic activities.[8] Therefore, attempts to remove CMS without an intervention to improve mobility will

inevitably fail. Conversely, gains in mobility do not automatically lead to reductions in CMS.[46] As increases in mobility are achieved, efforts should be made to integrate the new ROM into functional activities. Therefore, interventions aimed at improving ankle mobility and reducing CMS should follow a concurrent model with all qualities being developed simultaneously. This approach has been shown to reduce CMS in as little as two weeks.[3]

As the athlete acquires sufficient ankle dorsiflexion ROM, less time should be spent using mobility techniques. Stabilisation training should now be the main focus, with athletes learning to control the additional ankle mobility dynamically while minimising unnecessary CMS throughout the lower extremity. The goal is to re-integrate mobility gains into numerous lower extremity movement patterns, preventing the CMS identified during the screening process. When a particular CMS has been identified, athletes should be challenged to resist the dysfunctional motion, while utilising an ankle dorsiflexion movement strategy. Figure 6 provides an example exercise for this strategy.

In order to avoid excessive co-contraction patterns inhibiting full ROM, exercises aimed at improving movement pathways should start in a stable environment and progress through gradual reductions in stability. A simple example of this would be to start with bilateral squats, progressing to unilateral variations. In deciding when to progress, coaches should repeatedly observe similar ankle dorsiflexion angles, to what is demonstrated during the WBLT (representing functional capacity). This will indicate that the athlete is able to control their available ROM.

It is important to note that at no point during the re-training process should strength qualities be ignored. In order to safely perform within a high load environment, it is imperative that an athlete is sufficiently prepared to cope with the high force profiles associated with various athletic movements. Compensatory movement strategies are not exclusively caused by mobility restrictions, and may present during high load movement tasks when an athlete is unable to control the accompanying joint moments. It is therefore recommended that coaches maintain all necessary training methods throughout a neuromuscular re-education programme, as long as problematic CMS are not present and do not interfere with the re-training process.



Figure 6. Weight-bearing lunge with foot elevation. This exercise uses Reactive Neuromuscular Training[8] in order to educate the athlete to preferentially adopt an ankle dorsiflexion strategy as an alternative for a pronation strategy. The band provides a moderate knee valgus moment. The anti-pronators are in turn stimulated in order to overcome this moment, while full ankle dorsiflexion ROM is produced. This technique may also be used in more complex movement tasks

Conclusion

It was the objective of this article to present the influence that ankle dorsiflexion exerts on proximal joint segments. Increased pronation of the foot complex or excessive flexion at the hip and trunk may occur as a result of ankle hypomobility, depending on the constraints of the movement task. In each case, a rise in injury risk to numerous active and passive tissues throughout the lower extremity may occur.

When assessing ankle dorsiflexion ROM, weight-bearing assessments provide coaches with greater understanding regarding the capacity for active and passive components to restrict ROM. Alongside the WBLT, it is recommended that coaches attempt to identify an athlete's preferred movement strategy during an integrated movement task demanding high levels of ankle dorsiflexion ROM. Mobility and exercise-based interventions may then be designed based on the results of these assessments. For simultaneous improvements in ankle ROM and reductions in associated CMS, a concurrent approach should be employed, to remove myofascial or articular restrictions, facilitate stabilising capacity, and improve all essential strength qualities in order to tolerate high load environments.

'When assessing ankle dorsiflexion ROM, weight-bearing assessments provide coaches with greater understanding regarding the capacity for active and passive components to restrict ROM'

References

1. Anderson, M K, Hall, S J and Parr, G P. *Foundations of Athletic Training: Prevention, Assessment, and Management*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2013. pp. 249-250.
2. Backman, L J and Danielson, P. Low range of ankle dorsiflexion predisposes for patellar tendinopathy in junior elite basketball players: a 1-year prospective study. *American Journal of Sports Medicine*, 39(12): 2626-2633. 2011.
3. Bell, D R, Oates, C, Clark, M A and Padua, D A. Two- and 3-Dimensional knee valgus are reduced after an exercise intervention in young adults with demonstrable valgus during squatting. *Journal of Athletic Training*, 48(4):442-449. 2013.
4. Bennell, K, Talbot, R, Wajswelner, H, Techovanich, W, Kelly, D H. and Hall, A J. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Australian Journal of Physiotherapy*, 44(3): 175-180. 1998.
5. Collins, N, Teys, P. and Vicenzino, B. The initial effects of a Mulligan's mobilization with movement technique on dorsiflexion and pain in subacute ankle sprains. *Manual Therapy*, 9(2): 77-82. 2004.
6. Comerford, M J and Mottram, S L. Functional stability re-training: principles and strategies for managing mechanical dysfunction. *Manual Therapy*, 6(1): 3-14. 2001.
7. Comerford, M and Mottram, S. *Kinetic control: The management of uncontrolled movement*. Australia: Elsevier, 2012. pp. 455-458.
8. Cook, G, Burton, L, Kiesel, K, Rose, G, and Bryant, M F. Movement. Aptos, CA: *On Target Publications*, 2010. pp. 263-280.
9. Cosby, N L and Grindstaff, T L. Restricted ankle dorsiflexion self-mobilization. *Strength and Conditioning Journal*, 34(3):58-60. 2012.
10. Cowan, S M, Crossley, K M and Bennell, K L. Altered hip and trunk muscle function in individuals with patellofemoral pain. *British Journal of Sports Medicine*, 43(8): 584-588. 2008.
11. Crossley, K M, Zhang, W-J, Schache, A G, Bryant, A and Cowan, S M. Performance on the single-leg squat task indicates hip-abductor muscle function. *The American Journal of Sports Medicine*, 39(4): 866-873. 2011.
12. Delahunt, E, Cusack, K, Wilson, L. and Doherty, C. Joint mobilization acutely improves landing kinematics in chronic ankle instability. *Medicine and Science in Sports and Exercise*, 45(3): 514-519. 2013.
13. Denegar, C R, Hertel, J and Fonseca, J. The effect of lateral ankle sprain on dorsiflexion range of motion, posterior talar glide, and joint laxity. *Journal of Orthopaedic and Sports Physical Therapy*, 32(4): 166-173. 2002.
14. Dill, K E, Begalle, R, Frank, B, Zinder, S. and Padua, D.A. Altered knee and ankle kinematics during squatting in those with limited weight-bearing lunge ankle-dorsiflexion range of motion. *Journal of Athletic Training*, Epub ahead of print. 2014.
15. Earl, J E, Monteiro, S K and Snyder, K R. Differences in lower extremity kinematics between a bilateral drop-vertical jump and a single-leg step-down. *Journal of Orthopaedic and Sports Physical Therapy*, 37(5): 245–252. 2007.
16. Fong, C M, Blackburn, JT, Nocross, M F, McGrath, M and Padua, D A. Ankle-dorsiflexion range of motion and landing biomechanics. *Journal of Athletic Training*, 46(1): 5-10. 2011.
17. Gabbe, B J, Bennell, K L, Finch, C F, Wajswelner, H and Orchard, J W. Predictors of hamstring injury at the elite level of Australian football. *Scandinavian Journal of Medicine and Science in Sports*, 16(1): 7-13. 2006.
18. Gajdosik, R L, Vander Linden, D W, McNair, P J, Williams, A K and Riggin, T J. Effects of an eight-week stretching program on the passive-elastic properties and function of the calf muscles of older women. *Clinical Biomechanics*, 20(9): 973-983. 2005.
19. Gajdosik, R L, Allred, J D, Gabbert, H L and Sonsteng, B A. A stretching program increases the dynamic passive length and passive resistive properties of the calf muscle-tendon unit of unconditioned younger women. *European Journal of Applied Physiology*. 99(4): 449-454. 2007.
20. Green, T, Refshauge, K, Crosbie, J. and Adams, R. A randomized controlled trial of a passive accessory joint mobilization on acute ankle inversion sprains. *Physical Therapy*, 81(4): 984-994. 2001.
21. Griffin, LY, Albohm, M J, Arendt, E A, Bahr, R, Beynnon, B D, Demaio, M, Dick, R W, Engebretsen, L, Garrett, W E, Hannafin, J A, Hewett, T E, Huston, L J, Ireland, M L, Johnson, R J, Lephart, S, Mandelbaum, B R, Mann, BJ, Marks, P H, Marshall, SW, Myklebust, G, Noyes, F R, Powers, C, Shields, C, Shultz, S J, Silvers, H, Slauterbeck, J, Taylor, D C, Teitz, CC, Wojtys, EM and Yu, B. Understanding and preventing noncontact anterior cruciate ligament injuries: A review of the Hunt Valley II Meeting, January 2005. *The American Journal of Sports Medicine*, 34(9): 1512-1532. 2006.
22. Grindstaff, T L, Beazell, J R, Magrum, E M and Hertel, J. Assessment of ankle dorsiflexion range of motion restriction. *Athletic Training and Sports Health Care*, 1(1):7-8. 2009.
23. Guo, L-Y, Yang, C-H, Tsao, H, Wang, C-Y. and Liang, C-C. Initial effects of the ankle dorsiflexion mobilization with movement on ankle range of motion and limb coordination in young healthy subjects. *Formosan Journal of Physical Therapy*, 31(3): 173-181. 2006.
24. Halperin, I, Aboodarda, S.J, Button, D C, Andersen, L L. and Behm, D G. Roller massager improves range of motion of plantar flexor muscles without subsequent decreases in force parameters. *The International Journal of Sports Physical Therapy*, 9(1):92-102. 2014.
25. Hart, J M, Garrison, J C, Kerrigan, DC, Palmieri-Smith, R and Ingersoll, C D. Gender differences in gluteus medius muscle activity exist in soccer players performing a forward jump. *Research in Sports Medicine*, 15(2):15:147–155. 2007.
26. Hemmerich, A, Brown, H, Smith, S, Marthandam, S S and Wyss, U.P. Hip, knee, and ankle kinematics of high range of motion activities of daily living. *Journal of Orthopaedic Research*, 24(4): 770-781. 2006.
27. Hewett, T E, Ford, K R, Hoogenboom, B J, Myer, G D. Understanding and preventing ACL injuries: Current biomechanical and epidemiologic considerations – update 2010. *North American Journal of Sports Physical Therapy*, 5(4): 234-251. 2010.
28. Hoch, M C and McKeon, P O. Normative range of weightbearing lunge test performance asymmetry in healthy adults. *Manual Therapy*, 16(5): 516-519. 2011.
29. Hoch, M C, Staton, G S and McKeon, P O. Dorsiflexion range of motion significantly influences dynamic balance. *Journal of Science and Medicine in Sport*, 14(1): 90-92. 2011.
30. Hodges, PW. Core stability exercise in chronic low back pain. *Orthopedic Clinics of North America*, 34(2): 245-254. 2003.
31. Hollman, J H, Ginos, B E, Kozuchowski, J, Vaughn, A S, Krause, D A. and Youdas, JW. Relationships between knee valgus, hip-muscle strength, and hip-muscle recruitment during a single-limb step-down. *Journal of Sports Rehabilitation*, 18(1): 104-117. 2009.
32. Ireland, M L, Willson, J D, Ballantyne B T and Davis, IM. Hip strength in females with and without patellofemoral pain. *Journal of Orthopaedics in Sports and Physical Therapy*, 33(11): 671-676. 2003.
33. Johanson, M A, Cuda, B J, Koontz, J E, Stell, J.C. and Abelew, T.A. Effect of stretching on ankle and knee angles and gastrocnemius activity during the stance phase of gait. *Journal of Sport Rehabilitation*, 18(4):521-34. 2009.
34. Jones, R, Carter, J, Moore, P and Wills, A. A study to determine the reliability of an ankle dorsiflexion weight-bearing device. *Physiotherapy*, 91(4): 242-249. 2005.
35. Kaufman, K.R, Brodine, S K, Shaffer RA, Johnson, C W and Cullison, T R. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *American Journal of Sports Medicine*, 27(5):585–593. 1999.
36. Köhne, E, Jones, A, Korporaal, C, Price, JL, Brantingham, J W and Globe, G. A prospective, single-blinded, randomized, controlled clinical trial of the effects of manipulation on proprioception and ankle dorsiflexion in chronic recurrent ankle sprain. *Journal of American Chiropractor Association*, 44(5):7-17. 2007.

37. Konor, M M, Morton, S and Eckerson, J M. Reliability of three measures of ankle dorsiflexion range of motion. *The International Journal of Sports Physical Therapy*, 7(3): 279-287. 2012.
38. Kritz, M, Cronin, J. and Hume, P. The bodyweight squat: A movement screen for the squat pattern. *Journal of Strength and Conditioning*, 31(1): 76-85. 2009.
39. Loudon, J K and Bell, S L. The foot and ankle: an overview of arthrokinematics and seleceted joint techniques. *Journal of Athletic Training*, 31(2): 173-178. 1996.
40. Lundberg, A, Goldie, I, Kalin, B and Selvik, G. Kinematics of the ankle/foot complex: plantarflexion and dorsiflexion. *Foot Ankle*, 9(4): 194-200. 1989.
41. Macrum, E, Bell, D.R, Boling, M, Lewek, M. and Padua, D. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. *Journal of Sports Rehabilitation*, 21(3): 144-150. 2012.
42. Maitland C. Peripheral Manipulation. 2nd ed. Sydney, New South Wales, Australia: Butterworths. 1977.
43. Mauntel, T C, Begalle, RL, Cram, T R, Frank, B.S, Hirth, CJ, Blackburn, T. and Padua, DA. The effects of lower extremity muscle activation and passive range of motion on single-leg squat performance. *The Journal of Strength and Conditioning Research*, 27(7): 1813-1823: 2013.
44. McGill, S. Ultimate back fitness and performance. Canada: Backfitpro Inc, 2004.
45. Mølgaard, C, Rathleff, M S and Simonsen, O. Patellofemoral pain syndrome and its association with hip, ankle, and foot function in 16- to 18-year-old high school students: a single-blind case-control study. *Journal of the American Podiatric Medical Association*, 101(3): 215-222. 2011.
46. Moreside, J.M, and McGill, S.M. Improvement in hip flexibility do not transfer to mobility in functional movement patterns. *Journal of Strength and Conditioning Research*, 27(10): 2635-2543. 2013.
47. Mottram, S. and Comerford, M. A new perspective on risk assessment. *Physical Therapy in Sport*, 9(1): 40-51. 2008.
48. Mulligan, B R. Mobilisations with movement (MWM's). *Journal of Manual and Manipulative Therapy*, 1(4): 154-156. 1993.
49. Mulligan, BR. Manual Therapy: "NAGS", "SNAGS", "MWMS" etc. 3rd ed. Wellington: Plane View Services Ltd. 1995.
50. Neumann, D A. Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation. St. Louis: Mosby. 2002.
51. Novacheck, TK. The biomechanics of running. *Gait Posture*, 7(1): 77-95. 1998.
52. O'Shea, S. and Grafton, K. The intra and inter-rater reliability of a modified weight-bearing lunge measure of ankle dorsiflexion. Manual Therapy, 18(3): 264-268. 2013.
53. Padua, D A, Bell, D.R. and Clark, M.A. Neuromuscular characteristics of individuals displaying excessive medial knee displacement. *Journal of Athletic Training*, 47(5): 525–536. 2012.
54. Pope, R, Herbert, R. and Kirwan, J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in army recruits. *Australian Journal of Physiotherapy*, 44(3): 165-172. 1998.
55. Powers, C M. (2003) The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *Journal of Orthopaedic and Sports Physical Therapy*, 33(11): 639–646. 2003.
56. Preece, S J, Graham-Smith, P, Nester, C J, Howard, D, Hermens, H, Herrington, L. and Bowker, P. The influence of gluteus maximus on transverse plane tibial rotation. *Gait and Posture*, 27(4):616-621. 2008.
57. Presswood, L, Cronin, J, Keogh, J.W.L. and Whatman, C. Gluteus medius: Applied anatomy, dysfunction, assessment, and progressive strengthening. *Strength and Conditioning Journal*, 30(5):41-53. 2008.
58. Radford, JA, Burns, J, Buchbinder, R, Landorf, K.B. and Cook, C. Does stretching increase ankle dorsiflexion range of motion? A systematic review. *British Journal of Sports Medicine*, 40(10): 870-875. 2006.
59. Rees, S S, Murphy, A J, Watsford, M L, McLachlan, KA. and Coutts, A J. Effects of proprioceptive neuromuscular facilitation stretching on stiffness and force-producing characteristics of the ankle in active women. *Journal of Strength and Conditioning Research*, 21(2): 572-577. 2007.
60. Schoenfeld, B J. Squatting kinematics and kinetics and their application to exercise performance. *Journal of Strength and Conditioning Research*, 24(12):3497-3506. 2010.
61. Souza, R.B, Draper, C.E, Fredericson, M. and Powers, C M. Femur rotation and patellofemoral joint kinematics: a weight-bearing magnetic resonance imaging analysis. *Journal of Orthopaedic and Sports Physical Therapy*, 40(5): 277–285. 2010.
62. Starkey, C. and Ryan, J. Evaluation of Orthopedic and Athletic Injuries. Philadelphia: F. A. Davis Company. 2002.
63. Tiberio, D. The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. *Journal of Orthopaedic and Sports Physical Therapy*, 9(4): 160-165. 1987.
64. Tiberio, D. Evaluation of functional ankle dorsiflexion using subtalar neutral position: A clinical report. *Physical Therapy*, 67(6): 955-957. 1987.
65. Tiberio, D. Pathomechanics of structural foot deformities. *Physical Therapy*, 68(12): 1840-1849. 1988.
66. A - Tiberio, D, Bohanuon, RW and Zito, M A. Effect of subtalar joint position on the measurement of maximum ankle dorsiflexion. *Clinical Biomechanics* 4(3): 189-191. 1989.
67. Vicenzino, B, Prangley, I and Martin D. The initial effect of two Mulligan mobilization with movement treatment techniques on ankle dorsiflexion. Proceedings of the Australian Conference of Science and Medicine in Sport, Perth, WA, June 2001. Brisbane: Sports Medicine Australia. 2001.
68. Wahlstedt, C and Rasmussen-Barr, E. Anterior cruciate ligament injury and ankle dorsiflexion. *Knee Surgery, Sports Traumatology, Arthroscopy*. Epub ahead of print, 2014.
69. Whitting, JW, Steele, JR, McGhee, DE and Munro, B J. Passive dorsiflexion stiffness is poorly correlated with passive dorsiflexion range of motion. *Journal of Science and Medicine in Sport*, 16(2): 157-161. 2013.
70. Wikstrom, E A and Hubbard, T J. Talar positional fault in persons with chronic ankle instability. *Archives of Physical Medicine & Rehabilitation*, 91(8): 1267-1271. 2010.
71. Young, R, Nix, S, Wholohan, A, Bradhurst, R. and Reed, L. Interventions for increasing ankle joint dorsiflexion: a systematic review and meta-analysis. *Journal of Foot and Ankle Research*, 6(46). 2013.
72. Zazulak, BT, Ponce, P L, Straub, S J, Medvecky, M J, Avedisian, L. and Hewett, T E. Gender comparison of hip muscle activity during single-leg landing. *Journal of Orthopaedic and Sports Physical Therapy*, 35(5): 292–299. 2005

