DOI: 10.54254/2753-8818/89/2025.20323

Progress of the Exercise Therapy on Chronic Ankle Instability

Huaiyu Ren[1,a,*]

[1]University of Pittsburgh, 4200 Fifth Ave, Pittsburgh, PA 15260, USA
a. Hur15@pitt.edu
**corresponding author*

Abstract: This research delves into the effectiveness of various exercise therapies for Chronic Ankle Instability (CAI), a condition that frequently develops when initial ankle sprains are not adequately treated. CAI is characterized by repetitive sprains, joint instability, and reduced mobility, which can severely impact an individual's daily activities and sports performance. Different methods of rehabilitation, including muscle strengthening exercises, proprioceptive training, and balance improvement, were evaluated. The study emphasizes the advantages of combining traditional approaches such as resistance band exercises and newer techniques like blood flow restriction (BFR) training. These methods help enhance both strength and functionality in patients with CAI. Additionally, integrating proprioceptive exercises that focus on improving balance through unstable surface training has shown significant progress in restoring postural stability. Further, novel therapeutic interventions, including motor imagery, transcranial direct current stimulation (tDCS), and exergaming, demonstrate promising results in complementing traditional treatments. Ultimately, this review suggests a comprehensive rehabilitation plan that merges conventional and modern therapies to improve functional outcomes for individuals with CAI, though further research is necessary to optimize the combination of these therapies for long-term efficacy.

Keywords: The Chronic Ankle Instability, Proprioception training, Exercise therapy, Functional training.

1. Introduction

The ankle joint is a crucial weight-bearing joint in the lower limb, facilitating the transfer of body weight to the foot and ensuring balance and stability. Ankle sprains are prevalent sports injuries, and if inadequately addressed, they may result in recurring sprains and ultimately progress to chronic ankle instability (CAI). CAI denotes a condition characterized by persistent instability in the structure and function of the ankle joint, evidenced by recurrent sprains, a sensation of joint laxity, pain, and a reduction in mobility, and perhaps leads to joint deterioration and osteoarthritis, which significantly impair daily activities and sports performance. Failure to adequately treat or rehabilitate an acute sprain may result in around 40% of patients developing chronic ankle instability [1]. Individuals with persistent ankle instability should initially pursue non-surgical interventions, and if outcomes are inadequate, patients may then consider surgical options. Prevalent non-surgical treatment modalities encompass pharmacotherapy, physical factor therapy, manual therapy, and exercise therapy. Exercise therapy for chronic ankle instability has exhibited increased diversity as a result of the expansion of

DOI: 10.54254/2753-8818/89/2025.20323

research; however, its methodologies and the practical application value of the therapy still need to be summarized and analyzed. This article tries to synthesize research of exercise therapy on CAI conducted over the past five years, serving as a reference for future rehabilitation treatments and investigations related to CAI.

2. The etiology model of chronic ankle instability

In 2002, researchers classified chronic ankle instability into mechanical ankle instability (MAI) and functional ankle instability (FAI) according to its etiology, suggesting that recurring sprains are indicative of the simultaneous presence of both types of instability [2]. Certain scholars, utilizing Hertel's concept, discovered that some individuals noticed sensations of instability following ankle sprains, although did not encounter recurrent sprains. In 2011, Hiller presented a three-element subgroup model comprising mechanical instability, functional (perceptual) instability, and recurring ankle sprains [3]. In 2019, Hertel revised the paradigm of ankle instability, establishing a biopsychosocial framework [4]. CAI is defined primarily by pathological structural injuries, including those to the ATFL and CFL, alongside subsequent sensory, intuitive, and motor behavioral abnormalities, ultimately resulting in recurrent sprains or limb instability. Furthermore, personal and societal elements have been evaluated for the first time. Joint laxity is not the sole contributor to chronic ankle instability; therefore, it is increasingly essential to investigate factors such as neurophysiology.

3. Exercise therapy

3.1. Muscle strength training

Muscles serve as dynamic stabilizers for movement execution in the human body, and muscle strength correlates with movement quality. Studies indicate that individuals with CAI exhibit inadequate plantar flexor and eversion strength [5]. The strength training techniques for CAI patients are presently categorized into resistance training using resistance bands, strength training on unstable surfaces, isokinetic strength training, and blood flow restriction training, among others.

3.1.1. *Resistance-band*

A twelve-week study on resistance band training for ankle muscle strength in CAI patients randomly assigned subjects to the PBT (peroneus brevis) group and the PLB (peroneus longus) group, evaluating the impact of each muscle on the enhancement of patients' symptoms and functions. The findings indicated that both peroneus longus and peroneus brevis were efficacious for CAI patients; moreover, peroneus shown superior potential for enhancing strength and balance [6].

3.1.2. Blood flow restriction training

In recent times, blood flow restriction (BFR) training has become widely recognized as an innovative method, particularly favored by athletes and used extensively in rehabilitation settings. This technique involves the application of a tourniquet or inflatable cuff to the limb, which restricts venous outflow while allowing arterial inflow during exercise. This process leads to a localized decrease in oxygen supply, imposing metabolic stress on the muscle. This stress induces the recruitment of high-threshold motor units, with an emphasis on type II muscle fibers. This mechanism is critical for maximizing muscle engagement under such conditions, promoting muscle adaptation and growth. Additionally, BFR training has been shown to enhance corticospinal excitability, which increases the amplitude of motor-evoked potentials, thereby influencing motor function even in muscles beyond the direct site of restriction. Although BFR training has gained popularity, studies indicate that when applied as a

DOI: 10.54254/2753-8818/89/2025.20323

sole therapeutic method, it does not yield significant improvements in ankle muscle strength, dynamic balance, or overall physical performance in individuals with CAI. While this technique has shown promise in other areas, its effectiveness in isolation for CAI patients appears to be limited, requiring further exploration or combination with other therapeutic interventions to maximize results. However, its combination with other therapeutic exercises could offer more noticeable improvements in these areas [7]. Nonetheless, BFR in conjunction with exercise therapy can significantly enhance patients' ankle muscle strength and functional performance [8,9].

3.1.3. *Other muscle strength training*

Patients with CAI demonstrate reduced isometric torque in the ankle and hip joints compared to the unaffected population [10]. Thus, core training on an unstable surface can improve the dorsiflexion angle and muscular strength in individuals with CAI [11].

3.2. Proprioception training

Training focused on proprioception and neuromuscular control plays a crucial role in the rehabilitation of patients with CAI. Such exercises are highly effective in enhancing the dynamic control of posture, helping individuals regain stability and prevent further injuries. By targeting the body’s ability to sense joint positioning and improve coordinated muscle responses, this type of training significantly contributes to better overall balance and functional performance in CAI patients. The main balance training methods for CAI include anticipatory balance training, reactive balance training and other balance training methods such as the Whole-Body Variation.

3.2.1. *Anticipatory balance training*

Research demonstrates that individuals with CAI and systemic joint laxity have superior postural stability and muscle strength following balance training, in contrast to persons devoid of generalized joint hypermobility (GJH) [12].

3.2.2. *Reactive balance training*

A randomized controlled trial shown that jump stability training enhances the biomechanical mechanisms of jump-landing in individuals with CAI, consequently diminishing the risk of injury [13]. A study that applied stroboscopic glasses for balance training among patients revealed that the group using these glasses showed improvements in both valgus (rising from 150 milliseconds before initial exposure to 30 milliseconds afterward) and dorsiflexion angles (increasing from 30 milliseconds to 96 milliseconds post-exposure). Additionally, muscle activation in the peroneus longus increased (from 35 milliseconds pre-exposure to 5 milliseconds post-exposure), along with greater activation of the tibialis anterior muscle (extending from 0 to 120 milliseconds post-exposure) when compared to initial test results. The patients with CAI who underwent a 4-week rehabilitation program using these glasses also demonstrated changes in neuromechanics. These results suggest that incorporating stroboscopic glasses into rehabilitation routines may help CAI patients improve their landing mechanics and stability [14]. Research indicates that patients with unilateral chronic ankle instability may demonstrate bilateral open-eye static balance, functional performance, and sensory abnormalities, warranting more large-scale research to corroborate these results [15]. Research indicates that unilateral rehabilitative exercise can enhance the balance capability of the untrained limb in individuals with CAI, known as Cross-Education Balance Effects. Nevertheless, further research is required to ascertain which training program is most efficacious in generating cross-education effects [16].

3.2.3. *Other balance training*

Whole body vibration training (WBV) is presently a focal point of research. The primary idea is that vibration, as an external stimulus, can efficiently activate proprioceptors, augment the responsiveness of the central system, and improve neuromuscular coordination, ultimately boosting proprioception and postural stability [17,18]. A systematic evaluation examined the impact of WBV training on individuals with CAI. The primary finding of this study was the reach test of the SEBT. The findings demonstrated that the WBV group had enhancements in measures of the posterior-lateral, posterior-medial, and medial regions. There have been notable enhancements in muscle activation, strength, and proprioception metrics [19]. In comparison to solo WBV training, patients utilizing WBV in conjunction with shoes featuring an unstable surface had superior performance in jump assessments [20].

3.3. Combined treatment programs

3.3.1. *Acupuncture combined with exercise therapy*

Acupuncture, which originated in China and evolved over millennia, is a conventional therapy. The impact of acupuncture on CAI as an independent treatment remains ambiguous. Currently, it can be utilized as a combinatory treatment alongside exercise therapy. Studies indicate that the integration of acupuncture therapy with strength training can significantly improve anterior-posterior balance, ankle dorsiflexion, plantar flexion strength, and plantar flexion proprioception in individuals with CAI [21].

3.3.2. *Dry needling combined with exercise therapy*

Dry needling integrated with a proprioceptive training regimen to mitigate pain and improve functionality. The Dry Needling Balance Theory (DNET) asserts that enhanced proprioception in the lower limbs following dry needling results from modifications to the length-tension relationship of muscles and the application of mild acute discomfort to augment afferent signals from muscle spindles via the gamma motor system. The utilization of DNET in CAI patients may elucidate the mechanism behind the enhancement of descending cortical output, consequently improving sensorimotor function [22]. Randomized controlled research evaluated the efficacy of exercise therapy alone against exercise therapy supplemented with dry needling, indicating that the latter is more effective in reducing pain and enhancing function in individuals with CAI [23].

3.3.3. *Manual therapy combined with exercise therapy*

Manual therapy, which includes both graded joint mobilizations and mobilization with movement in weight-bearing and non-weight-bearing positions, primarily targets the improvement of ankle dorsiflexion. In a randomized controlled study, the effectiveness of combining Maitland mobilization with standard rehabilitation was evaluated against the outcomes of conventional rehabilitation alone in individuals with CAI. The results indicated that when Maitland mobilization was incorporated, there were significantly greater improvements in both balance and the range of motion in the ankle joint compared to rehabilitation without this mobilization technique. However, the increase in muscle strength did not show a statistically significant difference between the two groups [24].

3.3.4. Transcranial direct current stimulation (tDCS) combined with exercise therapy

tDCS is a non-invasive brain stimulation technique that can adjust cortical excitability, thereby addressing the negative neuroplasticity often linked to joint instability [25]. A double-blind

DOI: 10.54254/2753-8818/89/2025.20323

randomized controlled trial assessed the effects of high-definition tDCS (HD-tDCS) paired with short-foot exercise (SFE) training on postural control in individuals with CAI. Results showed that, compared to the sham-controlled group, the group receiving HD-tDCS with SFE experienced notable improvements in the Joint Position Reproduction (JPR) test, Y Balance Test, and Sensory Organization Test (SOT) at various time points [26]. Another randomized controlled study explored the impact of combining tDCS with foot core exercises (FCE) on sensory-motor functions of the foot, including toe flexor strength, passive ankle joint proprioception, and static balance. The findings revealed that, in contrast to the control group (sham + FCE), the tDCS + FCE group showed significant gains in toe flexor muscle strength and a reduced motion threshold for ankle eversion, although no significant difference was found in static balance [27]. In another study examining Bosu ball training, researchers sought to determine its effectiveness in reducing landing injuries for individuals with ankle instability from a kinematic standpoint. The data demonstrated a decline in both maximum angular velocity during ankle inversion and the plantar flexion angle at the point of peak inversion across both cohorts. By the seventh week, the group undergoing tDCS alongside Bosu ball training showed more notable changes in peak ankle inversion compared to those who did Bosu ball training alone. Both groups saw a meaningful reduction in their highest inversion angle ($p < 0.001$, $\eta 2p = 0.337$). Therefore, combining tDCS with Bosu ball exercises may offer better protection against landing-related injuries in CAI patients, ultimately lowering the risk of further damage [28].

3.4. Innovative interventions

3.4.1. *Motor imagery technique*

Motor imagery strategies include motor imagery and action observation and are often used in sports and rehabilitation settings. In recent years, some scholars have applied motor imagery techniques to the study of CAI rehabilitation therapy. Motor imagery is characterized as a cognitive and dynamic skill that encompasses the brain's representation of an activity, rather than the physical execution of the movement. In recent years, researchers have utilized movement imagery approaches to treat patients with persistent ankle instability. A systematic review and meta-analysis evaluating solo motor imaging, action observation, or their combination with standard care, in comparison to placebo interventions or no intervention. A meta-analysis (Nine studies, six examining healthy participants and three examining participants with an acute lateral ankle sprain, were included) indicates that motor imagery significantly influences lower limb strength. Nonetheless, the study exhibits limits and imprecision due to significant heterogeneity (I^2=73%) [29].

3.4.2. *Exergaming*

Motion-sensing games integrate video gaming with physical activity, enabling players to manipulate characters and perform tasks within the game via comprehensive bodily movements. Studies indicate that motion-sensing games enhance balance and coordination in CAI patients. Prevalent motion-sensing gaming systems comprise the Nintendo Wii, Xbox Kinect, among others. Patients enhance neuromuscular control and the response speed of the ankle joint by engaging in activities within the games, including balance assessments, gait simulations, and obstacle evasion. In contrast to conventional repetitive training, motion-sensing games can significantly improve patients' involvement and interest, rendering them especially appropriate for the rehabilitation of adolescents and sports. Motion-sensing games may replicate a range of workout activities, including jogging, leaping, and spinning, offering varied training techniques. Patients can attain functional rehabilitation while enjoying themselves. Research indicates that employing AVG in a 4-week home workout regimen may enhance balance and improve foot and ankle joint functionality. Additionally, it can boost positive motivation by increasing aspects such as interest, enjoyment, and perceived value or usefulness. At the same time, it helps to decrease feelings of stress and tension, which are common in children with CAI who require extended rehabilitation. This balanced approach not only makes therapy more engaging but also aids in long-term adherence to rehabilitative programs [30].

3.4.3. *Aquatic therapy*

A study contrasted aquatic therapy(n=15) with conventional land-based physical therapy(n=15) for athletes suffering from grade III ankle sprains. Aquatic therapy dramatically enhanced outcomes, including pain alleviation, dynamic balance, muscular strength, and general functionality. Athletes participating in aquatic therapy resumed sports more rapidly than those receiving conventional therapy (about 4.7 versus 7.7 weeks).This study emphasizes the advantages of water-based rehabilitation, particularly for athletes requiring reduced joint stress while preserving mobility [31]. A separate study examined balance training for athletes suffering from CAI. The study contrasted terrestrial with aquatic exercise settings, demonstrating that aquatic therapy, owing to the buoyancy of water, diminished joint stress and facilitated safer exercise performance. This enhanced balance, proprioception, and stability (Home). Aquatic activities provide a low-impact option for improving postural control, essential for athletes recuperating from CAI [32]. Aquatic therapy has been integrated with sophisticated methods, such as the creation of ankle rehabilitation robots intended to execute therapeutic activities in water [33]. This demonstrates the possibility for merging technology and hydrotherapy to facilitate recovery from ankle injuries by diminishing inflammation and enhancing range of motion.

4. Conclusion

The advancement of exercise therapy for Chronic Ankle Instability reveals an increasing body of research endorsing diverse therapeutic approaches focused on enhancing muscle strength, proprioception, and neuromuscular function. CAI marked by recurring sprains and functional instability of the ankle, may result in enduring repercussions if inadequately addressed. This review consolidates recent research on various exercise therapy methods, highlighting their effectiveness in enhancing functional results. Strength training of the muscles is essential for stabilizing the ankle and enhancing movement quality. Research has demonstrated that resistance band training significantly enhances balance and muscle strength in people with CAI. Moreover, blood flow restriction (BFR) training, when integrated with exercise therapy, improves functional performance, however its standalone advantages are constrained. Core exercise, particularly on unstable surfaces, enhances dorsiflexion angles and total muscle functionality in patients with CAI. Proprioceptive training, crucial for reinstating dynamic postural stability, encompasses a range of balance exercises. Methods such as anticipatory and reactive balance training have shown considerable enhancements in muscular strength and postural control in patients with CAI. Jump stability training mitigates the likelihood of reinjury by improving landing biomechanics, whereas advanced instruments such as stroboscopic glasses can alter neuromechanical responses, resulting in enhanced balance and muscle activation. Furthermore, integrated therapy strategies have proven to be especially efficacious. The combination of acupuncture and dry needling with exercise treatment improves balance, proprioception, and alleviates pain, offering a multimodal rehabilitation strategy. Likewise, manual treatment, including Maitland mobilization, when integrated with conventional exercise, markedly enhances range of motion and balance, although advancements in muscular strength may be less evident.

In summary, exercise therapy is fundamental to the management of CAI, providing various effective methods to enhance strength, proprioception, and functional performance. The integration of conventional exercises with novel therapies, including BFR training, stroboscopic balance training, and manual therapy, offers a holistic strategy for CAI rehabilitation. While many therapeutic

DOI: 10.54254/2753-8818/89/2025.20323

approaches show promise, further research is essential to determine the optimal combination of therapies and assess their long-term effectiveness in preventing recurrence and enhancing overall joint stability. This evidence-based framework is invaluable for healthcare providers aiming to refine treatment plans for patients suffering from CAI. By focusing on these areas, clinicians can develop more targeted and effective rehabilitation protocols that address both immediate and long-term needs.

References

[1] Herzog, M., Kerr, Z., Marshall, S., & Wikstrom, E. (2019). Epidemiology of ankle sprains and chronic ankle instability. Carolina Digital Repository (University of North Carolina at Chapel Hill). https://doi.org/10.17615/kye2-zr63

[2] Hertel, J. (2002). Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. PubMed, 37(4), 364–375. https://pubmed.ncbi.nlm.nih.gov/12937557

[3] Hiller, C. E., Kilbreath, S. L., & Refshauge, K. M. (2011). Chronic Ankle Instability: Evolution of the model. Journal of Athletic Training, 46(2), 133–141. https://doi.org/10.4085/1062-6050-46.2.133

[4] Hertel, J., & Corbett, R. O. (2019b). An updated model of chronic ankle instability. Journal of Athletic Training, 54(6), 572–588. https://doi.org/10.4085/1062-6050-344-18

[5] Hou, Z., Miao, X., Ao, Y., Hu, Y., Jiao, C., Guo, Q., Xie, X., Zhao, F., Pi, Y., Li, N., Zhang, Z., & Jiang, D. (2020). Characteristics and predictors of muscle strength deficit in mechanical ankle instability. BMC Musculoskeletal Disorders, 21(1). https://doi.org/10.1186/s12891-020-03754-9

[6] Ko, D., Choi, Y., & Lee, K. (2024). Effects of Peroneus Brevis versus Peroneus Longus Muscle Training on Muscle Function in Chronic Ankle Instability: A Randomized Controlled Trial. Healthcare, 12(5), 547. https://doi.org/10.3390/healthcare12050547

[7] Mahmoud, W. S., Radwan, N. L., Ibrahim, M. M., Hasan, S., Alamri, A. M., & Ibrahim, A. R. (2023). Effect of blood flow restriction as a stand-alone treatment on muscle strength, dynamic balance, and physical function in female patients with chronic ankle instability. Medicine, 102(44), e35765. https://doi.org/10.1097/md.0000000000035765

[8] Werasirirat, P., & Yimlamai, T. (2022). Effect of supervised rehabilitation combined with blood flow restriction training in athletes with chronic ankle instability: a randomized placebo-controlled trial. Journal of Exercise Rehabilitation, 18(2), 123–132. https://doi.org/10.12965/jer.2244018.009

[9] Liu, Y., & Wang, Y. (2024). Study on the effect of blood flow restriction training combined with IASTAM on ankle strength and function intervention in athletes with chronic ankle instability in sport dance events. BMC Sports Science Medicine and Rehabilitation, 16(1). https://doi.org/10.1186/s13102-024-00873-x

[10] Kosik, K. B., Johnson, N. F., Terada, M., Thomas, A. C., Mattacola, C. G., & Gribble, P. A. (2020). Decreased ankle and hip isometric peak torque in young and middle-aged adults with chronic ankle instability. Physical Therapy in Sport, 43, 127–133. https://doi.org/10.1016/j.ptsp.2020.02.014

[11] Alizamani, S., Ghasemi, G., & Nejadian, S. L. (2023). Effects of eight week core stability training on stable- and unstable-surface on ankle muscular strength, proprioception, and dorsiflexion in athletes with chronic ankle instability. Journal of Bodywork and Movement Therapies, 34, 6–12. https://doi.org/10.1016/j.jbmt.2023.04.005

[12] Hou, Z., Ao, Y., Hu, Y., Jiao, C., Guo, Q., Li, N., Jiang, Y., & Jiang, D. (2023). Balance training benefits chronic ankle instability with generalized joint hypermobility: a prospective cohort study. BMC Musculoskeletal Disorders, 24(1). https://doi.org/10.1186/s12891-023-06179-2

[13] Ardakani, M. K., Wikstrom, E. A., Minoonejad, H., Rajabi, R., & Sharifnezhad, A. (2019a). Hop-Stabilization training and landing biomechanics in athletes with chronic ankle instability: a randomized controlled trial. Journal of Athletic Training, 54(12), 1296–1303. https://doi.org/10.4085/1062-6050-550-17

[14] Lee, H., Han, S., & Hopkins, J. T. (2023). Balance training with stroboscopic glasses and neuromechanics in patients with chronic ankle instability during a Single-Legged Drop landing. Journal of Athletic Training, 59(6), 633–640. https://doi.org/10.4085/1062-6050-0605.22

[15] Hu, X., Feng, T., Li, P., Liao, J., & Wang, L. (2024). Bilateral Sensorimotor Impairments in Individuals with Unilateral Chronic Ankle Instability: A Systematic Review and Meta-Analysis. Sports Medicine - Open, 10(1). https://doi.org/10.1186/s40798-024-00702-y

[16] Lawry-Popelka, B., Chung, S., & McCann, R. S. (2022b). Cross-Education balance Effects after Unilateral Rehabilitation in Individuals with Chronic ankle instability: a Systematic review. Journal of Athletic Training, 57(11–12), 1055–1061. https://doi.org/10.4085/1062-6050-625-21

[17] Tan, J., Wu, X., Clark, C. C. T., Barton, V., Chen, S., Liu, S., Zhou, X., Xu, C., Ma, T., Qi, B., Han, J., & Zou, Y. (2022). The effect of whole body vibration on sensorimotor deficits in people with chronic ankle instability: A systematic review and meta-analysis. Clinical Rehabilitation, 36(8), 1016–1031. https://doi.org/10.1177/02692155221095651

[18] Coelho-Oliveira, A. C., Taiar, R., Pessanha-Freitas, J., Reis-Silva, A., Ferreira-Souza, L. F., Jaques-Albuquerque, L. T., Lennertz, A., Moura-Fernandes, M. C., Lacerda, A. C. R., Mendonça, V. A., Sañudo, B., Seixas, A., Boyer, F. C., Bernardo-Filho, M., Rapin, A., & Sá-Caputo, D. (2023). Effects of Whole-Body Vibration Exercise on Athletes with Ankle Instability: A Systematic Review. International Journal of Environmental Research and Public Health, 20(5), 4522. https://doi.org/10.3390/ijerph20054522

[19] Hoveidaei, A. H., Hashemi, S. M., Pazoki, S., Nakhostin-Ansari, A., Ghorbani, Z. M., Eghdami, S., Bahari, H., Sarzaeim, M., & Forogh, B. (2023). Effects of whole-body vibration on chronic ankle instability: a systematic review. Annals of Medicine and Surgery, 86(1), 401–411. https://doi.org/10.1097/ms9.0000000000001510

[20] Sofla, F. S., Hadadi, M., Rezaei, I., Azhdari, N., & Sobhani, S. (2021). The effect of the combination of whole body vibration and shoe with an unstable surface in chronic ankle instability treatment: a randomized clinical trial. BMC Sports Science Medicine and Rehabilitation, 13(1). https://doi.org/10.1186/s13102-021-00256-6

[21] Chang, S., Tan, Y., Cheng, L., Zhou, L., Wang, B., & Liu, H. (2024). Effect of strength training with additional acupuncture on balance, ankle sensation, and isokinetic muscle strength in chronic ankle instability among college students. Frontiers in Physiology, 15. https://doi.org/10.3389/fphys.2024.1324924

[22] Mullins, J. F., Nitz, A. J., & Hoch, M. C. (2019). Dry needling equilibration theory: A mechanistic explanation for enhancing sensorimotor function in individuals with chronic ankle instability. Physiotherapy Theory and Practice, 37(6), 672–681. https://doi.org/10.1080/09593985.2019.1641870

[23] Salom-Moreno, J., Ayuso-Casado, B., Tamaral-Costa, B., Sánchez-Milá, Z., Fernández-De-Las-Peñas, C., & Alburquerque-Sendín, F. (2015). Trigger point dry needling and proprioceptive exercises for the management of chronic ankle instability: a randomized clinical trial. Evidence-based Complementary and Alternative Medicine, 2015, 1–9. https://doi.org/10.1155/2015/790209

[24] Yin, Y., Yu, Z., Wang, J., & Sun, J. (2022). Effectiveness of the Rehabilitation Training Combined with Maitland Mobilization for the Treatment of Chronic Ankle Instability: A Randomized Controlled Trial. International Journal of Environmental Research and Public Health, 19(22), 15328. https://doi.org/10.3390/ijerph192215328

[25] Bruce, A. S., Howard, J. S., Van Werkhoven, H., Mcbride, J. M., & Needle, A. R. (2019). The effects of transcranial direct current stimulation on chronic ankle instability. Medicine & Science in Sports & Exercise, 52(2), 335–344. https://doi.org/10.1249/mss.0000000000002129

[26] Ma, Y., Yin, K., Zhuang, W., Zhang, C., Jiang, Y., Huang, J., Manor, B., Zhou, J., & Liu, Y. (2020). Effects of Combining High-Definition Transcranial Direct Current Stimulation with Short-Foot Exercise on Chronic Ankle Instability: A Pilot Randomized and Double-Blinded Study. Brain Sciences, 10(10), 749. https://doi.org/10.3390/brainsci10100749

[27] Xiao, S., Wang, B., Yu, C., Shen, B., Zhang, X., Ye, D., Deng, L., Xu, Y., Zhou, J., & Fu, W. (2022). Effects of intervention combining transcranial direct current stimulation and foot core exercise on sensorimotor function in foot and static balance. Journal of NeuroEngineering and Rehabilitation, 19(1). https://doi.org/10.1186/s12984-022-01077-5

[28] Huang, X., Gao, H., & Fu, H. (2024). Effects of transcranial direct current stimulation combined with Bosu ball training on the injury potential during drop landing in people with chronic ankle instability. Frontiers in Physiology, 15. https://doi.org/10.3389/fphys.2024.1451556

[29] Siemes, L. J., Van Der Worp, M. P., Nieuwenhuijzen, P. H. J., Stolwijk, N. M., Pelgrim, T., & Staal, J. B. (2023). The effect of movement representation techniques on ankle function and performance in persons with or without a lateral ankle sprain: a systematic review and meta-analysis. BMC Musculoskeletal Disorders, 24(1). https://doi.org/10.1186/s12891-023-06906-9

[30] Chuadthong, J., Lekskulchai, R., Hiller, C., & Ajjimaporn, A. (2023). A Home-Based exercise program with active video games for balance, motor proficiency, foot and ankle ability, and intrinsic motivation in children with chronic ankle instability: Feasibility randomized controlled trial. JMIR Serious Games, 11, e51073. https://doi.org/10.2196/51073

[31] Sadaak, M. M., AbdElMageed, S. F., & Ibrahim, M. M. (2024). Effect of aquatic versus conventional physical therapy program on ankle sprain grade III in elite athletes: randomized controlled trial. Journal of Orthopaedic Surgery and Research, 19(1). https://doi.org/10.1186/s13018-024-04855-0

[32] Naderi, A., & Ahi, K. (2024). Comparative Analysis of Land-Based vs. Water-Based Balance Training on Quality of Life and Physical and Psychological Deficits in Athletes with Chronic Ankle Instability: A Randomized Controlled Trial Assessing the Influence of Exercise Environment. Research Square (Research Square). https://doi.org/10.21203/rs.3.rs-4991597/v1

[33] Guzmán-Valdivia, C. H., Madrigal-López, O., Désiga-Orenday, O., Talavera-Otero, J., Brizuela-Mendoza, J. A., Chávez-Olivares, C. A., Cruz-Domínguez, O., Blanco-Ortega, A., Berumen-Torres, J. A., & Gómez-Becerra, F. A. (2021). Design, development and control of a therapeutic robot incorporating aquatic therapy for ankle rehabilitation. Machines, 9(11), 254. https://doi.org/10.3390/machines9110254