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Review

Effects of visual distraction and dual-task load on postural control and compensation in athletes with chronic ankle instability: a narrative review

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Abstract: Athletes performing in complex environments rely on multisensory integration to maintain dynamic postural stability, with visual input playing a critical role in movement regulation and environmental perception. This reliance may be particularly pronounced in athletes with chronic ankle instability (CAI), who often exhibit proprioceptive deficits, impaired neuromuscular control, and ligamentous laxity. In this narrative review, we aimed to examine how visual distraction and dual-task load influence postural control and compensatory movement strategies in athletes with CAI while discussing potential implications for assessment and rehabilitation. Relevant English-language literature was identified through searches of PubMed, Scopus, and Web of Science using keywords related to chronic ankle instability, visual disturbance, blurred vision, dual-task interference, and postural control. Evidence suggested that visual disturbance may impair environmental perception and dynamic stability, whereas uncorrected refractive errors may further exacerbate postural control deficits. Athletes with CAI frequently demonstrate compensatory neuromuscular adaptations, including increased proximal muscle activation and altered landing biomechanics, which may increase mechanical loading on the knee and hip joints. Under dual-task conditions, increased attentional and cognitive demands may further impair sensorimotor processing, reaction time, and dynamic postural regulation, leading CAI athletes to adopt hip-dominant stabilization strategies. Collectively, these findings highlight the importance of integrating visual, cognitive, and proprioceptive assessments into rehabilitation and injury prevention programs. In addition, dual-task and sport-specific training paradigms may help improve dynamic stability, neuromuscular control, and injury resilience in athletes with CAI.

Keywords: attention distraction; blurred vision; sensory integration; postural control; refractive error; neuromuscular control

1. Introduction

1.1. Visual input and feedforward motor control in sports

Athletes frequently encounter complex environments and multiple challenges in competitive settings, such as opponent movements, ball possession battles, tactical execution, and environmental distractions. To navigate these demands effectively, athletes must possess strong multisensory integration abilities, enabling them to extract accurate and reliable information from dynamic tasks and make real-time adjustments in movement and postural control [1]. In dynamic sports tasks, vision plays a critical role in postural balance, with clear vision and an intact peripheral visual field serving as key factors in maintaining postural stability [2]. Research has shown that impairments in visual acuity, such as blurred vision caused by refractive errors, can reduce contrast sensitivity, making it more difficult to detect subtle environmental changes [3], affecting postural control [4]. Therefore, vision serves not only as an essential source of sensory information for postural regulation, but also contributes to movement prediction and feedforward motor control during dynamic athletic tasks. Visual input enables athletes to anticipate environmental changes and adjust movement strategies prior to movement execution, thereby contributing to dynamic postural stability and neuromuscular control [5,6]. Researchers have reported that visual disturbances significantly impair athletes' balance, with even greater effects observed in individuals with chronic ankle instability (CAI) [7].

Due to deficits in proprioception, reduced tactile sensitivity, and inadequate muscle strength, individuals with CAI exhibit significantly lower static and dynamic postural stability than healthy populations [8]. Consequently, individuals with CAI may demonstrate increased reliance on visual cues during dynamic tasks as a compensatory adaptation to impaired proprioceptive processing and altered sensory reweighting, rather than vision serving as the sole or primary sensory mechanism for postural regulation [9].

1.2. Cognitive demands and dual-task interference in CAI

Attention refers to an individual's ability to process information and allocate cognitive resources. According to attention theory, cognitive processing capacity is inherently limited, making the distribution of attentional resources a key factor influencing motor performance [10]. Given these limitations, the allocation of attentional resources plays a crucial role in maintaining postural stability and integrating sensory information, particularly in individuals with CAI [11]. Under dual-task conditions, increased attentional demands and cognitive resource competition may impair postural regulation, resulting in reduced postural stability and an increased risk of ankle instability in CAI athletes [12]. When their ability to control posture is compromised, movement limitations may be further exacerbated [13]. Researchers have found that under attentional distraction, CAI individuals experience greater landing impact forces, more unstable movement control, and insufficient neuromuscular activation, which collectively increase their risk of injury [14]. Due to ankle instability, CAI individuals undergo significant adaptive changes in motor control strategies, including early muscle activation and increased reliance on proximal muscles (e.g., quadriceps) to compensate for functional deficits in distal ankle muscles. This pre-activation dependency enhances joint stability but may also lead to mechanical load redistribution, shifting stress away from the ankle while potentially increasing stress on the knee and hip joints [15]. Nozu et al. [16] reported similar findings, demonstrating significant differences in postural control strategies between CAI individuals and healthy controls, particularly in compensatory knee flexion adjustments. While these adaptive strategies may provide short-term benefits by absorbing landing impact forces and maintaining overall stability, they could simultaneously shift stress to proximal joints, increasing the risk of knee or hip injuries [17,18]. In summary, CAI individuals often adjust specific muscle activations (e.g., gluteal muscles) to compensate for ankle instability, making these adaptations crucial for improving dynamic balance [19].

1.3. Visual perturbation, compensatory strategies, and dynamic stability

Research suggests that blurred visual interference reduces athletes' sensitivity to environmental changes, thereby affecting dynamic postural control. Furthermore, dual-task conditions impose additional cognitive demands, exposing CAI individuals' reliance on compensatory strategies, such as increased hip and knee movements to offset ankle instability [20,21]. Collectively, the effects of visual perturbation, increased cognitive demands, and compensatory movement strategies suggest significant impairments in the dynamic postural stability of individuals with CAI.

1.4. Research gap and purpose of the review

Researchers have mostly examined visual disturbance, proprioceptive deficits, and dual-task interference independently, with limited attention given to the mechanistic interactions among these factors in athletes with CAI. Specifically, proprioceptive deficits and altered sensory reweighting may increase reliance on visual input for postural regulation, while visual perturbation and cognitive load under dual-task conditions may compete for limited attentional resources, thereby impairing sensorimotor integration and neuromuscular coordination. Consequently, a significant research gap remains regarding the mechanisms underlying compensatory movement strategies and dynamic postural instability under visually and cognitively demanding conditions. Therefore, we aim to synthesize the evidence regarding the effects of visual disturbance and dual-task demands on dynamic postural stability and compensatory neuromuscular strategies in athletes with CAI while proposing a conceptual framework to support future research and rehabilitation applications.

1.5. Methods

Relevant literature published in English was identified through searches of electronic databases, including PubMed, Scopus, and Web of Science. For the literature search, we focused on studies related to chronic ankle instability (CAI), visual distraction, blurred vision, dual-task interference, sensory reweighting, postural control, proprioception, and neuromuscular compensation. Keywords included combinations of “chronic ankle instability,” “dual-task,” “visual input,” “blurred vision,” “postural stability,” “sensory integration,” “neuromuscular control,” and “landing biomechanics.” Experimental and review studies entailing the effects of visual and cognitive demands on postural control and movement strategies were considered. Priority was given to studies involving athletic populations, dynamic postural tasks, landing biomechanics, and neuromuscular adaptations associated with CAI. Relevant articles were reviewed and synthesized narratively to provide an integrated overview of the relationships among sensory reweighting, attentional demands, and compensatory movement strategies in athletes with CAI.

2. Role of visual input in postural stability and neuromuscular control

In this section, we discuss the fundamental role of visual input in postural regulation, sensory reweighting, and neuromuscular coordination. We also provide the theoretical foundation for understanding how visual perturbation may influence dynamic stability and compensatory motor control in individuals with CAI.

2.1. Visual input and sensory reweighting in postural regulation

Postural stability is a fundamental function that enables the human body to maintain balance and motor control through the integration of multiple sensory systems, including visual, vestibular, and proprioceptive inputs [22,23]. Postural control is dynamically regulated through sensory reweighting, in which the central nervous system continuously adjusts the relative contribution of different sensory inputs according to task demands and environmental conditions [24]. Furthermore, the relationship between vision and postural stability is multifactorial and may involve not only visual input, but also gaze control, eye movement regulation, and fixational stability. Researchers have suggested that altered gaze stability and visual dependence may influence postural control under different sensory feedback conditions [25,26]. In addition, visual–vestibular interaction plays an important role in differentiating self-motion from external motion and maintaining postural stability through continuous sensory integration and sensory reweighting mechanisms [27]. Furthermore, vestibular contributions may become increasingly important when proprioceptive and visual information are compromised, particularly under dynamically challenging conditions.

Among these sensory systems, vision not only provides external environmental information but also plays a critical role in movement prediction, postural regulation, and feedforward motor control, enabling individuals to anticipate environmental changes and adjust movement strategies prior to movement execution to maintain dynamic stability. Santello et al. [6] reported that when visual input was removed, compensatory reliance on proprioceptive and vestibular systems increased. During landing tasks performed from different heights, the absence of visual input resulted in approximately 10% greater ground reaction forces, highlighting the important role of vision in pre-landing neuromuscular activation timing and motor control strategies.

2.2. Visual blur and postural stability

Empirical evidence has demonstrated that improvements in visual acuity through optical correction can significantly enhance postural stability, indicating the critical role of visual input in maintaining balance and neuromuscular coordination [28]. Under static standing conditions, blurred vision has been shown to significantly impair balance performance. Furthermore, when somatosensory and vestibular inputs are simultaneously disrupted, visual blur further exacerbates postural instability during dynamic tasks [29]. Buckley et al. [30] further demonstrated the essential role of vision in dynamic balance control, particularly in regulating the body center of mass (BCOM) and maintaining stability. Under visual occlusion conditions, individuals exhibit reduced movement velocity, increased instability, and deteriorated postural control, with the non-dominant limb demonstrating greater reliance on visual feedback. Similarly, Tomomitsu et al. [31] confirmed that visual feedback is necessary for maintaining balance and motor control during dynamic tasks and under unstable surface conditions.

2.3. Visual perturbation and neuromuscular control strategies

In addition to affecting postural stability, visual restriction may also alter neuromuscular control strategies. Mohapatra et al. [32] found that changes in visual conditions induced different anticipatory electromyographic (EMG) responses, suggesting that visual input influences neuromuscular activation timing and movement preparation strategies prior to postural adjustments. Moreover, uncorrected myopia has been associated not only with reduced static and dynamic postural stability but also with increased activation of the ankle musculature, indicating that decreased visual quality may alter neuromuscular control strategies to maintain balance [33]. Labanca et al. [34] further reported that, compared with eye-closed conditions, open-eye conditions significantly enhanced ankle stabilization strategies and muscle synergy control, further emphasizing the importance of visual input in neuromuscular coordination. Additionally, in the absence of visual information, co-contraction of the tibialis anterior and gastrocnemius muscles increases to enhance joint stiffness and maintain initial postural stability [35]. Collectively, these findings suggest that visual input not only influences postural stability but also contributes to dynamic balance maintenance through the regulation of neuromuscular activation and movement control strategies.

Experimental simulations using optical lenses of varying dioptric powers have demonstrated substantial modifications in postural control strategies. Edwards [36] reported that the application of +5.00D lenses resulted in a 50% increase in postural sway, while Paulus et al. [37] found that +4.00D and +6.00D lenses induced a 25% increase in instability. These findings indicate that alterations in refractive status exert a measurable effect on postural regulation. Moreover, Kim et al. [38] examined the effects of spherical lenses simulating myopic and hyperopic conditions on balance in young adults. The results revealed that at −0.50D myopia and +1.00D hyperopia, the postural stability index significantly declined. At −4.00D myopia and +1.50D hyperopia, the fall risk index markedly increased, underscoring the adverse impact of even mild refractive errors on balance and postural control, thereby highlighting the need for precise optical correction for the preservation of equilibrium.

2.4. Altered visual dependence and sensory reweighting deficits in CAI

However, individuals with chronic ankle instability (CAI) may exhibit altered sensory integration and increased dependence on visual input due to proprioceptive deficits. Researchers have suggested that peripheral joint injuries may disrupt afferent proprioceptive signaling, thereby increasing reliance on visual input for postural regulation [39]. In individuals with CAI, proprioceptive deficits have been associated with increased dependence on visual feedback during stability tasks [40]. Further investigations demonstrated that CAI individuals wearing stroboscopic glasses exhibited greater ankle inversion angles and increased peroneus longus activation during stance-to-cutting maneuvers, suggesting impaired sensory reweighting ability and reduced adaptability to visual perturbations [41]. Moreover, following a four-week stroboscopic balance training intervention, CAI individuals demonstrated significant improvements in postural control and reduced dependence on visual input, further supporting the critical role of visual feedback in postural stability [42].

In addition, individuals with CAI have been reported to exhibit reduced sensorimotor adaptability and impaired sensory reweighting capacity. Specifically, CAI individuals demonstrate diminished ability to appropriately regulate the contribution of visual, vestibular, and proprioceptive inputs, leading to greater dependence on visual and vestibular information during postural tasks [43]. Due to impaired proprioceptive function, individuals with CAI may increasingly depend on visual information as a compensatory resource for maintaining postural stability and motor control. However, when visual input is disrupted or attentional resources are limited, this excessive reliance on visual feedback may further impair sensory integration, compromise dynamic postural stability, and negatively affect athletic performance. Collectively, these findings suggest that altered sensory reweighting and increased visual dependence are key characteristics of CAI. Therefore, individuals with CAI, who commonly exhibit sensorimotor deficits and impaired neuromuscular control, may rely more heavily on visual feedback to maintain dynamic balance during functional and sport-specific tasks.

3. The relationship between ankle instability, proprioception, and postural stability

In this section, we focus on how proprioceptive deficits and mechanoreceptor dysfunction following ankle injury contribute to impaired neuromuscular control and altered postural regulation in individuals with CAI. Furthermore, we highlight the compensatory movement strategies and sensory adaptations that may emerge to maintain dynamic stability.

3.1. Mechanoreceptor injury and proprioceptive deficits following ankle sprain

Dynamic postural control plays a crucial role in injury prevention, as studies have indicated that enhanced postural stability reduces the recurrence of lower limb injuries [44]. Among musculoskeletal injuries, ankle sprains are the most common [45–48]. Most ankle sprains involve the lateral ligament complex, particularly the anterior talofibular ligament (ATFL) [49]. Following an ankle sprain, primary injury to the lateral ligament mechanoreceptors and surrounding sensory receptors may disrupt afferent proprioceptive feedback to the central nervous system, thereby impairing sensorimotor integration and neuromuscular coordination. Recurrent injuries and altered somatosensory input may further contribute to neuroplastic adaptations within sensorimotor networks and abnormalities in motor control signal integration, compromising dynamic postural stability and contributing to the development of CAI [50]. In cases of peripheral joint injuries, disruptions in afferent proprioceptive signaling may necessitate greater reliance on visual input for postural regulation. [39]. Consequently, individuals with CAI may increasingly depend on visual feedback to compensate for impaired proprioceptive function and maintain dynamic postural stability during functional activities.

3.2. Proprioceptive impairment and neuromuscular dysfunction in CAI

Proprioception plays a fundamental role in motor control by enabling the central nervous system to detect joint position and movement through sensory feedback [51]. However, proprioceptive impairment is a hallmark feature of ankle instability, as joint function and stability rely not only on ligamentous integrity but also on the mechanoreceptive function of muscle spindles [52]. Research by Fu and Hui-Chan [53] demonstrated that basketball players with impaired proprioception exhibit altered muscle contraction patterns compared to healthy athletes, such as simultaneous co-contraction of the ankle dorsiflexors and plantar flexors. This maladaptive strategy results in greater impact forces upon landing, increasing the risk of ankle sprains. Similarly, studies on volleyball players with functional ankle instability have reported reduced activation of the peroneus longus before ground contact in jump-landing tasks. As the peroneus longus serves as a primary evertor that prevents excessive and rapid inversion of the ankle, diminished activation of this muscle may negatively impact joint stability [54].

A systematic review and meta-analysis revealed that proprioceptive training programs effectively reduce the incidence of ankle sprains among athletic populations, irrespective of prior injury history [55]. Even in basketball players with recurrent ankle sprains, deficits in ankle repositioning accuracy and increased postural sway have been observed, with a significant correlation between the two. These findings underscore the need to incorporate proprioceptive and balance training into rehabilitation protocols for CAI [56]. Furthermore, a systematic review by Winter et al. [57] demonstrated that proprioceptive training yields a 46% improvement in proprioceptive function and a 45% enhancement in athletic performance. Such training has been shown to provide significant benefits for healthy individuals and clinical populations in improving sensory-motor function and movement efficiency.

3.3. Compensatory neuromuscular strategies and CoP alterations in CAI

Individuals with CAI typically exhibit decreased activation in ankle stabilizing muscles, as measured by surface electromyography (EMG) while demonstrating increased EMG activity in hip musculature. This altered activation pattern correlates with reductions in postural sway, indicating that CAI individuals adopt compensatory muscle recruitment strategies to integrate proximal muscle activation for stabilizing the unstable ankle joint [58]. Similar findings were reported by Morrison et al. [59], who observed that individuals with CAI exhibit abnormal plantar pressure distribution during running, particularly increased midfoot and lateral forefoot pressure. Studies have further demonstrated that center of pressure (CoP) variables are important indicators for assessing postural stability deficits in individuals with CAI. In particular, mediolateral (ML) CoP parameters, including root mean square (RMS), velocity, and integral values, appear to be especially sensitive in detecting postural control impairments in CAI populations [60]. Increased postural sway and altered CoP displacement patterns may reflect impaired proprioceptive feedback and deficits in neuromuscular control, thereby contributing to reduced dynamic postural stability during functional tasks. As a compensatory response to ankle instability, these individuals may exhibit gait modifications that increase mechanical loading on other lower extremity joints, particularly the knee and hip.

3.4. Ankle and hip strategies in postural regulation

Studies on neuromuscular activation patterns in CAI populations have shown significant reductions in the activation of key lower limb muscles, including the tibialis anterior, peroneus longus, lateral gastrocnemius, rectus femoris, biceps femoris, and gluteus medius. Additionally, CAI individuals exhibit delayed muscle onset activation and deficits in anticipatory activation across the ankle, knee, and hip musculature [61]. These findings highlight that proprioceptive impairment following ankle sprains leads to deficits in neuromuscular coordination, with CAI individuals displaying inadequate muscle activation, delayed responses, and compensatory recruitment patterns that compromise postural control and increase injury susceptibility. Proprioception is fundamental to postural control, particularly in ankle stability. The central nervous system integrates proprioceptive feedback from the ankle joint alongside other sensory inputs to regulate posture and maintain equilibrium. Effective proprioceptive training, whether passive or active, should emphasize enhancing the central nervous system's ability to interpret external stimuli to achieve optimal functional outcomes [62].

The coordination of multisensory feedback and movement degrees of freedom enables the human body to achieve effective postural control and stability. The modulation of movement across the ankle, knee, and hip is fundamental to maintaining a well-regulated postural control system [63]. Within dynamic postural stabilization strategies, the ankle and hip strategies are considered the primary mechanisms for maintaining equilibrium [64]. During quiet standing, postural control relies predominantly on ankle strategy, particularly in the absence of external perturbations [65]. Research has demonstrated that ankle movement and plantar flexion mobility are strongly associated with postural sway and balance performance, with dorsiflexor function playing an important role in postural regulation [66]. Di Giulio et a. [67] found that ankle muscles exhibit distinct yet cooperative roles in postural control. The tibialis anterior primarily provides proprioceptive input for balance regulation, while reciprocal inhibition mechanisms regulate the activation of the gastrocnemius and soleus muscles to promote stability. This intricate coordination among muscle groups enables precise adjustments to subtle center-of-mass shifts, contributing to the maintenance of postural stability.

Beyond ligamentous integrity and muscular activation, proprioceptive regulation is a critical frontline defense mechanism in ensuring ankle joint stability. Proprioception integrates external sensory inputs, including muscle length and tension, joint angles, and skin stretch, with muscle spindles serving as the principal proprioceptive receptors [68]. Research has demonstrated that muscle spindle function enables individuals to perceive ankle movement frequency and amplitude during quiet standing. By detecting subtle ankle oscillations, proprioceptive feedback facilitates precise motor responses to regulate muscular contraction and ankle torque, thereby ensuring postural stability [69]. Héroux et al. [70] further delineated the functional specialization of ankle muscles in postural stability. Influenced by muscle architecture, mechanical advantage, and motor unit recruitment characteristics, the soleus exhibits tonic activity and generates sustained force to stabilize the ankle joint and prevent postural sway. When standing, the body's center of mass exerts a forward inclination on the ankle joint, shortening the soleus and gastrocnemius muscles. As the body sways backward, these muscles lengthen. Notably, postural adjustments are not solely dependent on passive ankle stiffness but also rely heavily on anticipatory neuromuscular control mechanisms [71].

3.5. Proximal stabilization and compensatory movement adaptations in CAI

Collectively, these findings suggest that proprioceptive deficits following ankle injury not only impair postural stability but also alter neuromuscular coordination and movement regulation strategies. Because ankle strategy is highly dependent on accurate proprioceptive input, individuals with CAI may increasingly rely on proximal stabilization mechanisms, such as hip-dominant movement strategies, to maintain dynamic balance. Although these adaptations may temporarily enhance postural control, prolonged dependence on altered neuromuscular strategies may increase mechanical loading on adjacent joints and contribute to recurrent injury risk.

4. Dual-task interference in exercise performance and the highlighting of compensatory mechanisms

In this section, we examine how cognitive load and dual-task interference influence visuomotor processing, postural control, and neuromuscular coordination during athletic activities. Particular emphasis is placed on how athletes with CAI may rely on compensatory stabilization strategies under cognitively demanding conditions, thereby linking dual-task performance to injury-related biomechanics and dynamic stability.

4.1. Cognitive resource allocation and dual-task interference

Dual-task (DT) refers to the interference effects that arise when simultaneously performing two tasks, reflecting the inherent limitations of cognitive processing capacity [72]. Since attention plays a critical role in motor performance and information processing, attentional theories suggest that human cognitive resources are limited, and task performance is strongly influenced by attentional allocation and task demands [10,73,74]. Under dual-task conditions, competition for cognitive resources may impair information processing, postural regulation, and motor control, particularly when cognitive and motor tasks rely on overlapping attentional or perceptual demands. These interference effects are especially relevant in dynamic sports environments, where athletes must simultaneously process visual information, maintain postural stability, and execute complex motor actions. Consequently, insufficient attentional resources may compromise movement control and increase injury risk, particularly in athletes with CAI, who already exhibit sensorimotor deficits and impaired postural regulation.

4.2. Dual-task demands and visuomotor performance in sports

In dynamic and unpredictable sports environments, athletes are often required to simultaneously execute motor and cognitive tasks, such as running, passing, dribbling, visual searching, and decision-making, highlighting the importance of dual-task performance in sports [75]. Studies across team and individual sports have consistently demonstrated that increased cognitive load and attentional demands impair motor performance, visual search efficiency, reaction time, and postural regulation [76–79]. Athletes with lower dual-task ability exhibit greater performance deterioration under pressure, including significant reductions in passing accuracy, jump performance, and movement efficiency [77]. Furthermore, dual-task interference has been associated with disrupted visual search strategies, delayed reaction times, impaired proprioceptive information processing, and reduced agility [78–80]. Collectively, these findings suggest that increased cognitive and perceptual demands may compromise motor control and dynamic stability, particularly during tasks requiring simultaneous visuomotor processing and postural regulation. Evidence further suggests that neurocognitive deficits may contribute to altered neuromuscular control and compensatory movement strategies in individuals with CAI. Under dual-task conditions, cognitive load may heavily tax divided attention and attentional resource allocation, thereby impairing sensorimotor processing and postural regulation. These deficits may contribute to delayed reaction times, altered landing biomechanics, increased postural sway, and reduced dynamic stability during sport-related activities. Furthermore, recurrent ankle injuries and altered somatosensory input may induce neuroplastic adaptations within sensorimotor networks, potentially influencing motor control strategies and increasing susceptibility to recurrent injury [50].

4.3. Visual cognition and sport-specific attentional demands

These findings highlight the close relationship between visual cognition, attentional allocation, and dual-task performance in sports. During dynamic sports tasks, athletes must continuously process environmental information through visual search while executing motor actions, such as passing, landing, and directional changes. These complex visuomotor demands place substantial pressure on limited cognitive resources, making efficient attentional allocation critical for athletic performance and injury prevention [81]. High-level athletes demonstrate superior visual search efficiency and attentional regulation, enabling more stable motor performance under cognitively demanding conditions. Sports involving rapid visual search, continuous environmental monitoring, and dynamic directional changes, such as basketball, soccer, and volleyball, may impose greater visuocognitive demands and increase susceptibility to visual perturbation and dual-task interference during dynamic postural control [82–84].

4.4. Dual-task interference and injury-related biomechanics

Studies have shown that increased attentional demands and visual-cognitive interference negatively affect landing biomechanics, postural stability, and movement control [85–88]. Under dual-task conditions, athletes exhibit altered lower-limb biomechanics, including reduced knee flexion angles, elevated loading rates, increased vertical ground reaction forces (GRF), and impaired dynamic postural stability [86]. Similarly, visual distractions and secondary cognitive tasks have been shown to impair landing stability and increase injury-related biomechanical risk factors [87,89]. These findings suggest that when attentional resources are divided, athletes may experience reduced movement preparation and compromised motor regulation, creating conditions similar to unanticipated landing situations.

4.5. Expertise level and cognitive-motor adaptability

The influence of dual-task interference may also vary according to expertise level. Expert athletes tend to rely more on automated motor execution and flexible attentional allocation, whereas novice athletes depend more heavily on conscious motor control and explicit attentional focus [90,91]. Consequently, highly trained athletes may demonstrate greater adaptability under cognitively demanding conditions and maintain more stable postural control during dual-task performance. Collectively, these findings indicate that dual-task conditions impair cognitive and motor performances; however, systematic cognitive-motor training may improve attentional control, working memory, and overall movement efficiency [92].

4.6. Compensatory neuromuscular strategies in individuals with CAI

In summary, the cognitive load imposed by dual-task conditions significantly influences sports performance, particularly in information processing speed, reaction time, and motor control. For individuals with CAI, these cognitively demanding situations may further expose underlying compensatory movement strategies and deficits in postural regulation. Studies have demonstrated that individuals with ankle instability rely more heavily on proximal joint strategies, particularly at the hip, to attenuate landing impact forces and maintain dynamic stability [93,94]. Moreover, since impaired ankle function limits the ability to effectively absorb landing forces, CAI individuals compensate by utilizing the greater muscle strength and energy absorption capacity of proximal musculature, thereby redistributing mechanical loads during landing [95]. Compensatory strategies involving the knee and hip joints may enable CAI individuals to maintain movement patterns that superficially resemble those of healthy individuals, making instability difficult to detect through external observation alone. Hertel [96] proposed that recurrent ankle sprains and excessive ligamentous laxity contribute to increased reliance on proximal stabilization strategies, with the gluteus medius playing an important role in frontal-plane postural regulation. In addition, feedforward and feedback neuromuscular control mechanisms are essential for pre-landing preparation and post-landing stabilization, contributing to the maintenance of dynamic balance [6,97]. Gribble and Robinson [21] further demonstrated that individuals with CAI exhibit greater activation of the peroneus longus and gluteus maximus during the pre-landing phase of a single-leg lateral jump task, indicating compensatory neuromuscular adjustments in distal and proximal musculature. Collectively, these findings suggest that CAI individuals rely on altered neuromuscular coordination and hip-dominant stabilization strategies to compensate for impaired ankle function, particularly under cognitively demanding or dual-task conditions.

4.7. Proximal stabilization and neuromuscular compensation during landing

In terms of neuromuscular activation, individuals with CAI require greater inter-joint and inter-muscular coordination to maintain ankle positioning and dynamic stability during landing tasks. Studies have demonstrated that CAI individuals exhibit increased activation of proximal musculature, particularly the gluteus maximus, prior to landing, suggesting an enhanced reliance on hip-dominant stabilization strategies to optimize center-of-mass control and lower-limb stability [98]. In addition, the peroneus longus plays a critical role in resisting excessive ankle inversion during landing and contributes substantially to lateral ankle stabilization and injury prevention [99–102].

4.8. Clinical implications and conceptual framework

These findings suggest that sports injuries not only impair local ankle function but also alter overall lower-limb neuromuscular coordination patterns. To preserve movement efficiency and athletic performance, individuals with CAI may adopt compensatory coordination strategies across joints and muscle groups, thereby masking underlying instability during functional tasks. Consequently, conventional clinical assessments may not adequately identify deficits associated with recurrent ankle instability. Figure 1 illustrates the proposed biomechanical framework underlying sensory reweighting deficits and compensatory neuromuscular control in athletes with CAI, highlighting the interactions among proprioceptive impairment, increased visual dependence, dual-task interference, and proximal stabilization strategies.

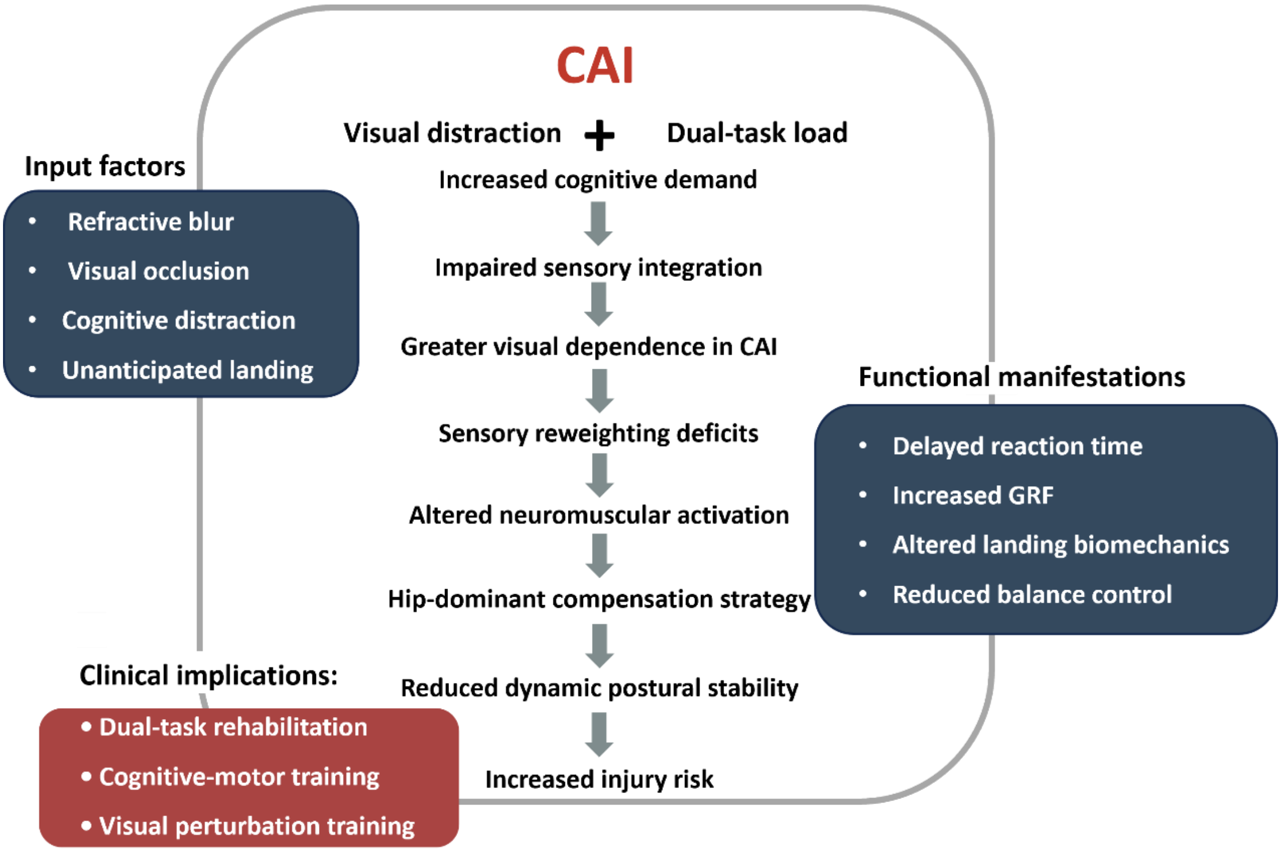

Figure 1. Proposed biomechanical framework of sensory reweighting deficits and compensatory neuromuscular control in athletes with chronic ankle instability.

Because dual-task paradigms more closely resemble real-world sports environments, they may better reveal hidden impairments in postural regulation and neuromuscular control in athletes with CAI. Moreover, prolonged reliance on compensatory movement strategies may progressively increase mechanical stress on adjacent joints and further compromise ankle function over time. Therefore, in future studies, researchers should investigate the long-term consequences of compensatory neuromuscular adaptations and determine whether persistent reliance on proximal stabilization strategies contributes to progressive ankle instability. From a practical perspective, rehabilitation and sports training programs should incorporate cognitive-motor challenges, visual perturbation paradigms, and dual-task conditions to better simulate competitive environments, thereby improving attentional control, sensory integration, dynamic stability, and injury resilience in athletes with CAI.

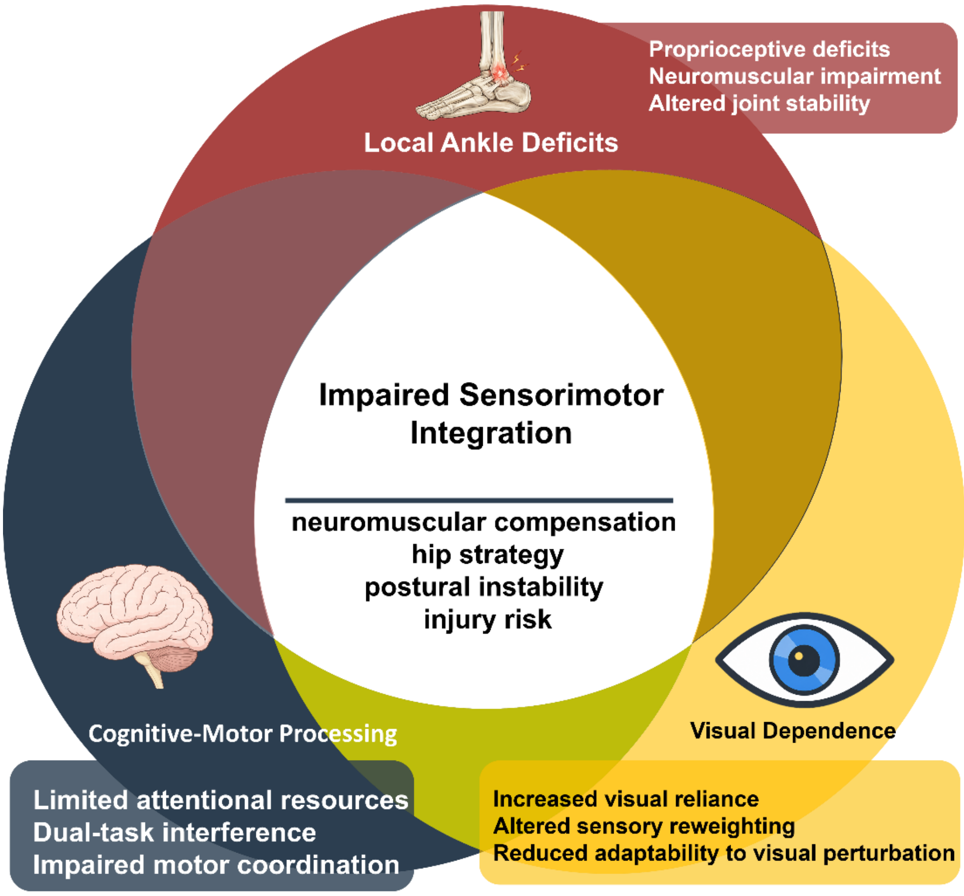

Figure 2. Proposed biomechanical framework of altered sensory reweighting and compensatory neuromuscular control in athletes with chronic ankle instability.

Figure 2 further illustrates the proposed interaction framework among local ankle deficits, cognitive-motor demands, and altered visual dependence in athletes with CAI. Proprioceptive impairment and neuromuscular dysfunction may increase reliance on visual feedback, while dual-task interference and increased attentional demands may further impair sensorimotor integration and movement coordination. Together, these interacting factors may contribute to altered sensory reweighting, impaired dynamic postural stability, and increased reliance on compensatory neuromuscular and hip-dominant stabilization strategies during sport-specific tasks in athletes with CAI.

Collectively, these findings suggest that athletes with CAI may exhibit altered interactions among proprioceptive deficits, sensory reweighting impairments, visual dependence, and cognitive-motor interference, which together may compromise dynamic postural stability and contribute to compensatory neuromuscular adaptations during sport-specific tasks.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare no conflict of interest.

Author contributions

Chi-Wei Chang and Jian-Zhi Lin developed the original research inquiry; Yi-Chin Chung collected references; Chi-Wei Chang and Jian-Zhi Lin wrote and reviewed the manuscript. All authors approved the final version of this manuscript.

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