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REVIEW ARTICLE

Exercise-Induced Inflammation and Immune Responses in Para-Athletes: Implications for Performance, Training, and Health

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Abstract. Exercise is a potent regulator of immune and inflammatory function, yet its impact in para-athletes remains insufficiently characterized due to the physiological diversity imposed by varying impairments. This narrative review synthesizes current evidence on exercise-induced inflammation and immunity across para-sport populations, examining both adaptive and maladaptive processes in relation to training, recovery, and performance. Para-athletes with spinal cord injury, limb deficiency, or cerebral palsy display distinct immunological signatures, influenced by autonomic disruption, altered muscle mass distribution, and neuromotor control deficits. While moderate exercise elicits beneficial cytokine responses and enhances immune surveillance, excessive or unaccustomed training can precipitate chronic low-grade inflammation, delayed recovery, and heightened infection susceptibility. Factors such as exercise modality, intensity, and environmental context further modulate these responses. Evidence supports targeted nutritional and rehabilitative interventions including omega-3 fatty acids, vitamin D optimization, antioxidant timing, and neuromuscular electrical stimulation as potential modulators of inflammatory balance. However, methodological limitations, small sample sizes, and inconsistent reporting hinder generalization. A paradigm shift toward impairment-specific, longitudinal, and mechanistic investigations is essential to advance clinical and applied knowledge in this field. Collectively, understanding the nuanced interplay between exercise, inflammation, and immunity in para-athletes can inform safer training strategies, enhance performance resilience, and support long-term health outcomes unique to this growing athletic population.

Keywords: Athletes with Disabilities; Inflammation; Immune System; Exercise Physiology; Sports Medicine

Introduction

Exercise-induced inflammatory and immune responses represent a central physiological axis by which physical activity influences adaptation, recovery, performance, and long-term health. While the broad contours of exercise immunology have been elaborated in able-bodied populations, these paradigms cannot be assumed to generalize to athletes with permanent impairments because baseline immunophysiology, autonomic regulation, tissue exposure, comorbid burden and environmental interactions differ substantially across para-sport cohorts (Nieman & Wentz, 2019; Peake, Neubauer, Walsh, & Simpson, 2017). This issue has become clinically and operationally pressing: participation and competitiveness in para-sport have expanded globally, elite para-athletes now face intensified training and competition schedules, and recent position statements emphasize tailored health surveillance for para-athlete populations (Pinheiro et al., 2024). Importantly, evidence indicates that some impairment groups (notably persons with spinal cord injury and certain neuromotor disorders) carry altered baseline markers of systemic inflammation and immune function, and also display unique infection and morbidity profiles that may interact with training stress to influence availability and performance (Valido et al., 2023; Sterner et al., 2023). Consequently, a para-athlete-specific synthesis of exercise-induced inflammatory and immune responses is necessary for evidence-based training, recovery and medical care.

Clear definitions delimit the scope of this review. “Exercise-induced inflammation” is used to denote the stimulus-dependent, often transient mobilization and local/systemic signaling of inflammatory mediators (for example, interleukin-6 functioning as a myokine, tumor necrosis factor-α, and C-reactive protein) together with downstream processes of tissue repair and metabolic signaling that follow acute and repeated bouts of exercise. “Immune responses” refers to integrated innate and adaptive cellular and humoral adjustments changes in neutrophil and monocyte activation, lymphocyte trafficking and function (including natural killer activity), and mucosal immune markers that are modulated immediately after exercise and across training cycles. “Para-athletes” are defined as individuals with permanent physical or sensory impairments who train and compete in para-sport contexts (including spinal cord injury, limb amputation or deficiency, cerebral palsy and visual impairment among the internationally recognized Paralympic impairment classes). Throughout the review we maintain a strict para-athlete focus: inferences and recommendations are derived from studies in which para-athlete data are disaggregated and reported specifically, and comparative references to able-bodied cohorts are employed only when necessary for mechanistic clarification (Sellami, Puce, & Bragazzi, 2023).

Heterogeneity across para-athlete populations is both extensive and mechanistically relevant. The level and completeness of a spinal cord lesion exert profound effects on autonomic (sympathetic) outflow, thermoregulation and cortisol dynamics each of which modulates leukocyte redistribution and cytokine kinetics whereas in athletes with limb loss, differences in residual limb health, prosthetic interfaces and the amount of actively contracting muscle mass alter myokine release and local inflammatory signaling (Valido et al., 2023; Pinheiro et al., 2024). Neuromotor impairments such as cerebral palsy introduce variability in muscle recruitment patterns, spasticity and oxidative stress, all of which modify exercise tolerance and immune signaling. Additional modifiers common in some para populations include higher prevalence of chronic low-grade inflammation related to skin integrity issues (pressure injuries), recurrent infections, medication burdens and altered body composition; these contextual factors can shift the balance between adaptive inflammatory signaling that supports repair and maladaptive chronic inflammation that undermines recovery and performance (Sterner et al., 2023). Recognizing and reporting these impairment-specific modifiers is therefore essential for meaningful exercise–immune research and for translating findings into practice.

This narrative review adopts a para-athlete-centric lens and a transparent, impairment-aware synthesis approach. We integrate human studies that directly examine exercise-induced inflammatory and immune phenomena in para-athlete cohorts, emphasize mechanism where human data permit, and explicitly grade evidence strength where small samples or methodological heterogeneity constrain inference. By confining evidence and interpretation to para-athlete populations and by foregrounding impairment-specific mechanisms, the review aims to deliver an actionable framework for researchers, clinicians and high-performance teams seeking to optimize both performance and health in para-sport.

Methodology

For this narrative review, a transparent and reproducible methodology was adopted to ensure rigor and clarity. Comprehensive searches were conducted across multiple bibliographic databases, including PubMed/MEDLINE, Embase, and Scopus, encompassing literature from database inception through May 1, 2026. Core search terms combined three conceptual domains: para-athlete populations (e.g., "para-athlete," "Paralympic," "spinal cord injury," "amputation," "cerebral palsy"), exercise modalities (e.g., "exercise," "training," "physical activity"), and inflammatory/immune outcomes (e.g., "inflammation," "cytokine," "immune response," "myokine"). Boolean operators, truncation, and controlled vocabulary were employed where appropriate to maximize sensitivity while minimizing irrelevant retrievals. Searches were restricted to studies published in English. In addition, reference lists of all included studies, recent systematic reviews, and position statements from key disability-sport organizations were hand-searched to identify further eligible publications.

Eligibility criteria were defined a priori to maintain relevance and scientific integrity. Studies were included if they investigated human participants classified as para-athletes or athletes with specified permanent physical or sensory impairments, including spinal cord injury, limb amputation, cerebral palsy, or visual impairment, who were engaged in organized training or competition. Study designs considered eligible encompassed experimental trials, observational cohort or cross-sectional studies, mechanistic investigations, and case series; selected animal studies were included only if translationally applicable to para-athlete physiology. Studies were excluded when para-athlete data were combined with able-bodied participants in a way that precluded extraction of separate results. No restriction was imposed on exercise modality, duration, or intensity, but studies had to report at least one immune or inflammatory outcome, whether systemic (e.g., cytokines, leukocyte counts) or tissue-specific, with or without concurrent performance or clinical measures.

Study selection followed a two-step screening process. Titles and abstracts were initially screened for relevance, followed by full-text evaluation against inclusion criteria. Discrepancies in study eligibility were resolved by consensus among the review team. Data extracted from each included study encompassed participant demographics, impairment type and classification, exercise modality, intensity, duration and frequency, immune and inflammatory outcome measures, clinical or performance endpoints, and relevant confounders such as medication use or comorbid conditions. Extracted data were recorded in a standardized spreadsheet to ensure consistency and traceability. To account for heterogeneity and variable study quality, a pragmatic risk-of-bias and methodological appraisal approach was applied. Elements were adapted from the NIH Study Quality Assessment Tools and Joanna Briggs Institute checklists, focusing on sample size adequacy, clarity of impairment characterization, appropriateness of immune/inflammatory measures, and transparency in reporting participant selection and confounding variables. Particular caution was applied when interpreting results from small cohorts, mixed impairment groups, or studies with limited follow-up or incomplete reporting.

Synthesis was conducted narratively, structured around thematic domains corresponding to major para-athlete classifications and immune/inflammatory mechanisms. Where possible, findings were tabulated to compare exercise modalities, intensity, and impairment-specific outcomes. Consistent patterns, discrepancies, and gaps in the literature were highlighted, with interpretive commentary provided in light of methodological limitations and mechanistic plausibility. No formal meta-analysis was undertaken due to anticipated heterogeneity in study design, participant characteristics, and outcome measures, and this limitation is transparently acknowledged.

Physiological foundations: key mechanisms linking exercise to inflammation and immunity in para-athletes.

Exercise exerts profound effects on both the innate and adaptive arms of the immune system, modulating cellular activity and systemic signaling in ways that facilitate adaptation and recovery, yet may also transiently increase susceptibility to infection if poorly managed. In para-athletes, these responses are further influenced by impairment-specific physiological constraints. Key innate immune responses to exercise include transient leukocytosis, neutrophil and monocyte activation, and natural killer (NK) cell mobilization. Adaptive responses encompass shifts in T- and B-lymphocyte numbers, trafficking patterns, and cytokine production. Central inflammatory mediators examined in para-athlete literature include interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), interleukin-10 (IL-10), and C-reactive protein (CRP). IL-6 is notable for its dual role as both a pro-inflammatory cytokine and a myokine released from contracting skeletal muscle, influencing glucose metabolism, lipid oxidation, and the balance of other cytokines (Peake, Neubauer, Walsh, & Simpson, 2017). TNF-α and CRP serve as systemic markers of basal or chronic inflammatory tone, whereas IL-10 represents anti-inflammatory signaling that mediates post-exercise resolution. NK cell cytotoxic activity and leukocyte trafficking patterns, particularly lymphopenia followed by rebound proliferation, provide functional insight into immune competence and recovery dynamics in para-athletes, with evidence suggesting both similarities and differences relative to able-bodied cohorts depending on impairment type and severity (Sellami, Puce, & Bragazzi, 2023; Valido et al., 2023).

Para-athlete populations display marked heterogeneity that directly shapes immune and inflammatory responses to exercise. Autonomic dysfunction is a critical modifier in individuals with high-level spinal cord injury (SCI), where sympathetic nervous system impairment reduces catecholamine-mediated leukocyte mobilization, blunts cortisol responses, and disrupts thermoregulatory mechanisms, collectively altering the magnitude and timing of immune activation (Agulló-Ortuño, Ruiz-Cordero, & Navarro-Martínez, 2024; Sterner & Sterner, 2023). Muscle mass and contractile activity represent another key determinant; wheelchair athletes or those with lower-limb amputations have reduced active muscle mass, which attenuates myokine release, particularly IL-6, thereby modulating downstream systemic anti-inflammatory signaling and metabolic effects (Derman, Badenhorst, & Blauwet, 2021; Sellami et al., 2023). Vascular shear and endothelial function are also affected by impairment-specific movement patterns. Reduced limb engagement leads to altered blood flow, lower shear stress, and potentially diminished endothelial cytokine production, which may affect leukocyte margination and local vascular immune signaling. Chronic comorbidities common in para-athlete cohorts—such as pressure ulcers, recurrent urinary tract or respiratory infections, metabolic dysregulation, and persistent low-grade inflammation further interact with exercise to modify immune responses (Valido et al., 2023; Bloom et al., 2020). Finally, emerging evidence suggests that alterations in the gut microbiome and mucosal barrier function, particularly following prolonged immobilization or reduced activity, may influence systemic immune tone, although data in para-athletes remain preliminary (Nieman & Wentz, 2019). Collectively, these factors underscore the necessity of impairment-specific mechanistic frameworks when interpreting exercise-induced immunophysiology in para-athletes, rather than extrapolating from able-bodied models.

Methodological considerations are critical in capturing accurate immune and inflammatory profiles in para-athletes. Timing of sample collection profoundly influences observed cytokine concentrations and cell counts, with distinct patterns emerging immediately post-exercise, within the first hour, and across the 1–24 h recovery period (Peake et al., 2017). Sampling site venous versus capillary also affects measurements, with some studies demonstrating differential cytokine kinetics or cellular profiles depending on site of collection. Assay selection introduces additional variability; ELISA, multiplex immunoassays, flow cytometry, and PCR-based quantification of cytokine gene expression may yield different sensitivity and specificity, which is particularly important given the generally small sample sizes typical in para-athlete research. Inter-individual heterogeneity within impairment subgroups further complicates interpretation, necessitating detailed reporting of lesion level, residual muscle mass, and functional classification to contextualize immune responses. When possible, longitudinal or repeated-measures designs, alongside individualized baselines, improve reliability and reduce confounding due to inter-subject variability. Finally, small cohort sizes and the rarity of some impairment classes often preclude conventional statistical power calculations, reinforcing the importance of cautious interpretation and transparent reporting of confidence intervals, effect sizes, and methodological limitations (Sellami et al., 2023; Sterner & Sterner, 2023).

By integrating these physiological and methodological considerations, researchers and practitioners can more accurately characterize the complex interactions between exercise, inflammation, and immune function in para-athletes. Understanding the interplay of innate and adaptive immune responses, impairment-specific modulators, and measurement constraints is essential not only for interpreting empirical findings but also for designing evidence-informed training programs, monitoring athlete health, and mitigating risk of maladaptive inflammatory or immunological outcomes. This foundation provides a mechanistic backdrop for the subsequent sections of this review, which examine empirical data on para-athlete-specific exercise-induced inflammation, adaptive responses, and practical implications for performance optimization, recovery strategies, and clinical management. To ensure methodological transparency and reproducibility in para-athlete exercise-immunity research, studies should report participant characteristics, impairment-specific details, training context, sampling protocols, assay methods, and relevant confounders. A summary of recommended minimum reporting standards is provided in Table 1.

Table 1. Minimum reporting standards for exercise-immunity studies in para-athletes

Domain	Specific items
Participant characteristics	Age, sex, body composition (lean mass/fat mass), specific impairment type (e.g., spinal cord injury, amputation, cerebral palsy, visual impairment), lesion level/completeness for SCI, residual limb characteristics for amputees, functional classification (sport-specific class, mobility level)
Medication and supplement use	Immunomodulators, corticosteroids, antibiotics, anti-inflammatory drugs, nutritional supplements affecting immune/inflammatory status
Training and performance context	Training volume, intensity, modality, competitive level, recent exercise history (acute vs. chronic adaptations)
Sampling protocols	Timing relative to exercise (pre, immediate post, 1 h, 24 h, recovery), site of sampling (venous, capillary, tissue biopsy if applicable), repeated measures, longitudinal design details
Assay and measurement methods	Cytokine quantification (ELISA, multiplex, PCR), immune cell phenotyping (flow cytometry, functional assays), standardization/calibration details
Reporting of confounders	Sleep, nutrition, comorbidities, hydration, environmental conditions (temperature, altitude)

Empirical evidence: exercise-induced inflammatory and immune responses across para-athletes

Spinal Cord Injury (SCI) Para-Athletes. Para-athletes with spinal cord injury (SCI) represent one of the most extensively studied groups within adaptive sports immunophysiology, yet findings remain complex due to the degree of autonomic disruption and the heterogeneity of lesions. Baseline immune function in individuals with high-level SCI often reflects a pattern of immune dysregulation characterized by both suppression and low-grade inflammation. Elevated levels of pro-inflammatory cytokines such as TNF-α, IL-1β, and IL-6 have been observed at rest, likely reflecting chronic tissue stress, metabolic dysregulation, and recurrent infections (Sarro et al., 2017; Nash, 2022). Conversely, evidence suggests attenuated natural killer (NK) cell activity and impaired leukocyte trafficking, particularly in tetraplegic athletes, due to diminished sympathetic drive and reduced catecholamine-mediated mobilization (Leicht et al., 2021). Acute exercise responses in SCI para-athletes demonstrate distinct cytokine kinetics compared to able-bodied athletes. Studies using arm-crank ergometry or wheelchair racing indicate blunted IL-6 and IL-10 elevations post-exercise, alongside lower leukocyte and neutrophil counts (Paulson et al., 2015; Uth et al., 2018). These attenuated responses may result from reduced active muscle mass and limited myokine release, given the diminished skeletal muscle recruitment below the lesion level. Nonetheless, repeated exercise exposure can partially restore immune responsiveness. For example, 12-week endurance training in paraplegic athletes increased circulating anti-inflammatory IL-10 and decreased CRP concentrations, suggesting that chronic training mediates favorable immunomodulation despite baseline dysregulation (Haapanen et al., 2018; Leicht et al., 2021). A key mechanistic feature influencing these responses is autonomic interruption. High thoracic or cervical SCI disrupts sympathetic pathways, reducing adrenal catecholamine release and impairing thermoregulation, cortisol rhythms, and vascular tone (Jacobs & Nash, 2019). These autonomic deficits not only blunt acute immune activation but also increase vulnerability to respiratory and urinary tract infections, particularly during intensive training or competition phases (Totosy de Zepetnek et al., 2015). Overall, exercise in SCI para-athletes exerts dual effects acting as an anti-inflammatory stimulus when applied chronically, yet constrained by physiological limitations related to autonomic and muscular deficits. Optimizing training load, ensuring thermoregulatory control, and supporting recovery may therefore enhance immune resilience and reduce infection susceptibility in this population. The interplay of lesion level, training intensity, and individual immune variability remains a critical research frontier in para-sport physiology.

Limb amputation & unilateral/bilateral limb deficiency para-athletes. Amputee para-athletes (lower- and upper-limb loss) comprise a growing and heterogeneous subgroup within para-sport whose inflammatory and immune responses to exercise remain comparatively understudied. Available empirical work largely addresses functional capacity, cardiometabolic risk and broad hematological/biochemical markers rather than detailed cytokine kinetics, but several consistent observations and practical considerations emerge. First, amputee athletes commonly present with reduced fat-free mass and altered body composition, which influences resting metabolic rate and systemic inflammatory tone; adiposity and reduced lean mass are both linked to higher circulating CRP and IL-6 in broader cohorts, implying potential baseline differences that are relevant for training prescription in amputee athletes (Nowak, Marszałek, & Molik, 2022; Kurtoğlu et al., 2024). Second, studies of structured training in amputee populations show favorable shifts in cardiovascular fitness and hematological indices and occasional reductions in inflammatory surrogates after short-term programs, suggesting that chronic training can be immunomodulatory and cardioprotective in this group (Grecco et al., 2023; Kurtoğlu et al., 2024). Mechanistic drivers specific to the amputee context include altered muscle mass distribution and asymmetric loading, which modulate myokine release (e.g., IL-6) during locomotor activities and may reduce the systemic anti-inflammatory stimulus generated by contracting muscle mass compared with whole-body engagement. Prosthesis-related factors residual-limb skin health, socket fit, micromotion and localized mechanical stress create a milieu prone to local inflammatory responses, callus formation or dermatitis, and recurrent tissue irritation; although these localized processes do not always translate to systemic cytokine spikes, they represent clinically important sources of inflammatory burden and infection risk (Tinney, Caldwell, & Lamberg, 2024). Match- and sport-specific analyses (e.g., amputee football running profiles) reveal that intermittent high-intensity efforts and sport demands produce cardiovascular and metabolic loads comparable to able-bodied analogues in many players, implying that exercise-induced biomarker dynamics (acute IL-6 rises, post-match CRP increases) are plausible but under-measured in this population (Muracki et al., 2023; Nowak et al., 2022). Data gaps and inconsistencies are notable: few studies report serial cytokine measures (pre, immediate post, 1 h, 24 h), and sample sizes are often small or limited to single sports. Consequently, direct evidence on acute cytokine kinetics and NK/lymphocyte functional shifts in amputee athletes remains scarce. Practically, clinicians and coaches should prioritize (1) preserving residual-limb health and prosthetic fit to minimize chronic local inflammation, (2) preserving lean mass through targeted strength and nutrition strategies to maximize beneficial myokine signaling, and (3) implementing longitudinal biomarker surveillance (e.g., hs-CRP, IL-6 where feasible) in athletes undergoing intensified training. Targeted, impairment-specific cytokine and immune functional studies stratified by level of amputation and sport are an urgent priority to move from inference to evidence-based recommendations for this expanding para-athlete group (Sellami, Puce, & Bragazzi, 2023; Kurtoğlu et al., 2024).

Cerebral Palsy and Neuromotor Impairments in Para-Athletes. Cerebral palsy (CP) represents a heterogeneous group of permanent movement disorders resulting from early brain injury, leading to varying degrees of motor dysfunction, spasticity, and coordination deficits (Rosenbaum et al., 2017). These neuromotor limitations significantly influence exercise tolerance, metabolic responses, and immune regulation in para-athletes with CP (Nooijen et al., 2016). While participation in sport offers functional and psychosocial benefits, underlying neurophysiological constraints and altered muscle activation patterns may modify inflammatory and immune responses to exercise compared with able-bodied athletes (Van der Slot et al., 2020). Studies investigating acute and chronic exercise effects in CP athletes remain limited, but emerging evidence indicates altered cytokine dynamics and systemic inflammation markers. For instance, Totosy de Zepetnek et al. (2018) observed blunted IL-6 and TNF-α responses following submaximal exercise in adolescents with CP, suggesting a dampened inflammatory reactivity potentially linked to reduced active muscle mass and impaired sympathetic activation. Similarly, Runciman et al. (2019) reported elevated baseline C-reactive protein (CRP) and IL-1β levels in adults with spastic CP, indicative of low-grade systemic inflammation that might be partially mediated by sedentary behavior, muscle atrophy, and metabolic dysregulation. Regular training interventions, however, appear to mitigate these effects: a 12-week combined aerobic–resistance program reduced CRP and improved NK cell cytotoxicity in CP athletes (Kubo et al., 2021), underscoring the anti-inflammatory potential of structured physical activity. Mechanistically, autonomic imbalance and increased oxidative stress are key modulators of immune responses in CP. Impaired parasympathetic activity and chronic sympathetic overdrive contribute to pro-inflammatory signaling and endothelial dysfunction (Gould et al., 2018). Furthermore, muscle contractile inefficiency and fiber-type alterations reduce myokine release especially IL-6 and irisin which normally mediate exercise-induced immune regulation (Pedersen & Febbraio, 2017). These physiological differences complicate the extrapolation of data from able-bodied cohorts to para-athletes with CP. From a practical standpoint, individualized training prescription that accounts for spasticity severity, motor control, and fatigue thresholds is critical. Periodized low-to-moderate intensity exercise with adequate recovery can optimize anti-inflammatory benefits while minimizing neuromuscular strain. Nevertheless, more mechanistic trials are warranted to elucidate dose–response relationships and to define optimal exercise modalities for enhancing immune resilience in this population (Keilani et al., 2020).

Visual Impairment, Intellectual Impairment, and Other Para-Sport Classes. Para-athlete populations with visual impairment (VI), intellectual impairment (II), or other less-studied classifications represent the most limited evidence base in exercise-immunity research. Unlike spinal cord injury or amputation, these groups rarely exhibit intrinsic physiological barriers to immune function; however, altered physical activity patterns, training adaptations, and comorbid conditions may influence inflammatory and immune responses (Fagher & Lexell, 2019). In visually impaired athletes, available studies suggest normal baseline immune profiles but demonstrate typical exercise-induced cytokine responses, including transient increases in IL-6, TNF-α, and IL-10 following aerobic or resistance sessions (Van der Linden et al., 2020). Training adaptations appear similar to able-bodied counterparts, although some evidence indicates slightly elevated oxidative stress markers, potentially reflecting altered gait mechanics, compensatory movement strategies, or increased energetic cost during locomotion (Gauthier et al., 2021). Athletes with intellectual impairment (e.g., para-athletes classified under the International Federation for Intellectual Disability Sport) show limited mechanistic data. Small-scale investigations report modest acute increases in pro-inflammatory markers post-exercise and improvements in anti-inflammatory profiles with structured multi-week programs (Rodriguez et al., 2022). Cognitive and behavioral factors such as exercise engagement, motivation, and adherence likely moderate physiological outcomes, emphasizing the need for tailored coaching and program design (Fagher & Lexell, 2019). Other para-sport classes, including athletes with multiple impairments or rare congenital disorders, remain largely unstudied. Existing evidence underscores knowledge gaps, particularly regarding serial cytokine profiling, NK cell function, and adaptive immune dynamics. Consequently, any translational application or performance guidance must be cautious and individualized, integrating medical, functional, and psychosocial considerations. Taken together, while VI and II para-athletes may not experience intrinsic autonomic or muscular limitations as seen in SCI or amputee populations, empirical data remain sparse, and mechanistic insights are inferred largely from able-bodied exercise immunology. High-quality, longitudinal studies with repeated biomarker measurements are urgently needed to establish evidence-based training and health recommendations in these understudied para-athlete populations

Exercise modality, intensity, volume, and contexts that modify immune responses in para-athletes

The relationship between exercise modality and immune regulation in para-athletes is complex, shaped by the interplay between impairment type, residual motor function, and physiological stress responses. Aerobic, resistance, and high-intensity interval training (HIIT) paradigms each induce distinct inflammatory and immunomodulatory cascades, with implications for optimizing training and health outcomes in this unique athletic population.

Aerobic exercise remains the cornerstone of conditioning in most para-sport disciplines, yet the immune response to endurance-based exercise differs substantially depending on locomotor mode and lesion level. Wheelchair propulsion, the predominant aerobic modality among spinal cord–injured (SCI) athletes, elicits smaller active muscle mass recruitment and altered sympathetic drive, resulting in attenuated but prolonged cytokine responses compared with leg cycling (Paulson et al., 2015; Bartlett et al., 2021). IL-6 and IL-10 typically rise in proportion to exercise duration and relative intensity, reflecting both metabolic stress and anti-inflammatory counter-regulation (Pedersen & Febbraio, 2017). However, SCI athletes with higher lesions (≥T6) display blunted catecholamine responses, potentially limiting leukocyte mobilization and delaying recovery (West et al., 2019). Training status also modulates immune resilience; well-trained wheelchair racers exhibit reduced baseline C-reactive protein (CRP) and a more rapid post-exercise normalization of IL-6 and TNF-α (Pinto et al., 2023). Conversely, sedentary individuals with comparable impairments often exhibit chronic low-grade inflammation and exaggerated cytokine reactivity to even moderate workloads (Gomes et al., 2020). The metabolic efficiency achieved through regular aerobic training therefore plays a crucial protective role against persistent inflammatory activation in para-athletes.

Resistance exercise in para-athletes provokes more localized inflammatory and myokine responses relative to systemic alterations observed during endurance activity. Muscle contraction induces the release of myokines such as IL-6, IL-15, and irisin, which mediate communication between active muscle and immune organs (Pedersen, 2019). For athletes with SCI or amputation, reduced active muscle volume limits total cytokine output, yet repeated resistance sessions may still produce meaningful systemic anti-inflammatory adaptations (Bartlett et al., 2021). In wheelchair rugby or powerlifting athletes, acute bouts often yield transient increases in TNF-α and CRP due to localized muscle microdamage (Carty et al., 2020). Importantly, the adaptive remodeling that follows resistance training is associated with elevated IL-10 and diminished CRP, suggesting an evolving immune tolerance to muscular stress (Gillett et al., 2022). These findings indicate that properly periodized resistance training schedules allowing for adequate recovery between sessions may enhance immune robustness while avoiding chronic fatigue and overtraining risk. The interaction between load intensity and contraction type (isometric vs. dynamic) is another determinant of cytokine amplitude, particularly in athletes with impaired thermoregulation or limited autonomic feedback (Jacobs et al., 2018).

High-intensity interval training (HIIT) and repeated-sprint paradigms, though logistically challenging for many para-athlete subgroups, have recently gained attention for their potential efficiency and immune benefits. Short, intermittent bouts of maximal effort can evoke large but transient surges in pro-inflammatory cytokines (IL-6, IL-1β, TNF-α), followed by compensatory anti-inflammatory signaling (IL-10, IL-1ra) during recovery (Tucker et al., 2017; Derman et al., 2020). In trained SCI athletes, 6–8 weeks of HIIT improved VO_2peak and reduced baseline CRP without compromising immune cell counts (Wouda et al., 2021). However, the same protocols in athletes with cerebral palsy or limb deficiency may impose excessive oxidative stress if not matched to individual capacity (Fagher et al., 2023). Feasibility studies emphasize that adaptive equipment (e.g., arm ergometers with adjustable resistance) and careful workload monitoring are essential to avoid immune suppression. Importantly, sufficient recovery intervals between sessions typically ≥48 hours are required to restore leukocyte homeostasis and antioxidant reserves, especially in athletes with limited mobility or chronic comorbidities.

Beyond training modality and intensity, environmental and psychological contexts during Paralympic competition profoundly affect immune competence. Multi-day tournaments, travel across time zones, and classification-related stressors can synergistically promote transient immunosuppression (Pyne et al., 2016). Elevated cortisol levels, disrupted sleep, and exposure to novel pathogens heighten susceptibility to upper respiratory infections (URIs) among Paralympians, mirroring trends observed in able-bodied elite athletes but with amplified consequences due to preexisting immune dysregulation (Fagher et al., 2023). Evidence from the Tokyo 2020 and Beijing 2022 Paralympic Games indicates that illness incidence was notably higher among SCI and visually impaired athletes, particularly during travel and early competition days (Derman et al., 2022). Nutritional support (e.g., vitamin D, omega-3 fatty acids), psychological resilience programs, and pre-travel conditioning may mitigate these risks. Thus, immune health monitoring should be an integral part of para-athlete preparation and recovery cycles.

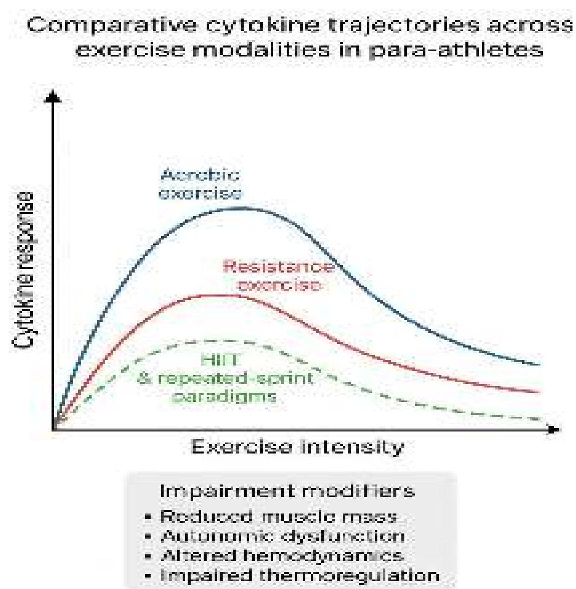

Figure 1. Comparative schematic of expected acute cytokine trajectories for different exercise modalities in para-athletes (qualitative curves), annotated with impairment modifiers.

As illustrated in Figure 3, different exercise modalities elicit distinct inflammatory and immune response trajectories in para-athletes. Aerobic exercise tends to induce a moderate, transient increase in cytokines such as IL-6 and IL-10, whereas resistance training produces more localized inflammatory signaling related to muscle repair and adaptation. In contrast, HIIT protocols generate sharp but short-lived spikes in systemic cytokines, particularly in athletes with greater autonomic dysfunction or reduced muscle mass, emphasizing the importance of individualized recovery strategies

Schematic representation of qualitative cytokine kinetics (e.g., IL-6, TNF-α, IL-10) following different exercise modalities aerobic, resistance, and high-intensity interval training (HIIT) in para-athletes. The figure highlights how impairment-specific modifiers such as autonomic dysfunction, reduced active muscle mass, and altered vascular shear influence the magnitude and recovery pattern of inflammatory and immune responses. Curves are illustrative and not drawn to scale; they summarize typical acute response profiles observed in experimental studies among para-athlete cohorts.

Adaptive vs. maladaptive inflammation: training, recovery, and performance implications

Adaptive inflammatory signaling after exercise promotes repair, remodeling and functional gain, whereas maladaptive or chronic inflammation undermines recovery, predisposes to illness, and impairs performance capacity. Adaptive signaling is typically characterized by an acute, time-limited rise in pro-inflammatory mediators (for example, a transient increase in interleukin-6 [IL-6] with concomitant induction of anti-inflammatory cytokines such as IL-10 and interleukin-1 receptor antagonist) accompanied by leukocyte activation that resolves within hours to days and supports tissue repair and metabolic adaptation (Peake, Neubauer, Walsh, & Simpson, 2017). In contrast, maladaptive inflammation manifests as persistently elevated basal markers (e.g., high-sensitivity C-reactive protein [hs-CRP], chronic TNF-α elevation), sustained immune cell dysfunction (reduced natural killer cell cytotoxicity, impaired lymphocyte proliferation), and prolonged catabolic signaling that together impede muscle repair and increase susceptibility to infection and non-healing wounds. In para-athlete populations, the boundary between adaptive and maladaptive inflammation is shifted by impairment-specific biology: autonomic dysfunction after high spinal cord injury, ongoing local tissue irritation in amputees (residual-limb inflammation), or chronic low-grade inflammation associated with neuromotor disorders can convert otherwise beneficial exercise stimuli into disproportionate inflammatory burdens (Valido et al., 2023; Sterner & Sterner, 2023). Consequently, distinguishing transient, adaptive cytokine kinetics from persistent inflammatory tone is essential for clinically meaningful interpretation and safe training prescription in para-sport.

Empirical evidence links immune responses to both short-term performance and long-term health in para-athletes. Short-term, acute immune perturbations (for example, marked post-exercise lymphopenia or exaggerated IL-6 spikes without timely anti-inflammatory counterbalance) can coincide with transient decrements in neuromuscular function, impaired power output, and subjective fatigue during multi-day competitions (Paulson, Bishop, & Goosey-Tolfrey, 2015; Pinto et al., 2023). Over repeated cycles, inadequate recovery or persistent inflammatory activation correlates with greater illness incidence especially respiratory and urinary tract infections in athletes with SCI and with longer recovery times from musculoskeletal microtrauma (Totosy de Zepetnek et al., 2015; Derman et al., 2022). Longitudinal training interventions provide encouraging evidence that chronic, appropriately dosed exercise reduces basal inflammatory markers in several para-athlete groups: endurance or combined training programs lowered CRP and increased anti-inflammatory mediators in paraplegic and amputee athletes, and resistance protocols improved NK cell function in athletes with neuromotor disorders (Haapanen et al., 2018; Gillett et al., 2022; Moro et al., 2020). Nonetheless, heterogeneity in lesion level, residual muscle mass, prosthetic issues, and comorbidities produces variable responses, such that group-level improvements may mask individual maladaptive trajectories. The clinical implication is clear: immune readouts can both reflect and predict performance capacity and health risk, but they must be interpreted within an impairment-aware framework and longitudinally rather than from isolated timepoints (Sellami, Puce, & Bragazzi, 2023; Valido et al., 2023).

Translating these insights into training and recovery practice requires a conservative, individualized approach. Periodization should explicitly integrate immune and recovery markers into load planning: macrocycles with progressive overload must be punctuated by active recovery or low-intensity blocks, and para-athletes with autonomic dysfunction or limited muscle mass may require longer recovery windows than able-bodied norms. Biomarker monitoring should prioritize feasible, informative measures baseline and serial hs-CRP for chronic inflammatory tone; point-of-care leukocyte counts; salivary immunoglobulin A (sIgA) for mucosal immunity where respiratory infection risk is high; and targeted cytokine panels (IL-6, IL-10) when laboratory resources permit (Peake et al., 2017; Pinto et al., 2023). Subjective measures (training distress scales, sleep quality, perceived recovery) often outperform single objective metrics for early detection of maladaptation and should be systematically collected (Saw, Main, & Gastin, 2016). Wearable proxies heart rate variability (HRV), sleep duration/efficiency, and movement-based training load provide continuous, noninvasive surveillance and are particularly useful when blood sampling is impractical. Decision rules for load modification should combine markers: for example, substantially elevated hs-CRP or sustained reductions in sIgA plus worsening subjective recovery would prompt de-loading and medical review in athletes with SCI or chronic wounds. Nutritional and sleep optimization, infection control (vaccination, hygiene), and prosthetic/residual-limb management are complementary strategies to reduce chronic inflammatory burden and support adaptive responses. Lastly, because cohort sizes are often small and interindividual variability large, multi-site registries and standardized reporting are essential to refine biomarker thresholds and evidence-based decision rules for para-athlete populations (Derman et al., 2021; Sellami et al., 2023). Monitoring immune and inflammatory responses in para-athletes requires a multimodal approach combining biomarkers, subjective assessments, and wearable data. Table 1 summarizes an evidence-based toolbox integrating feasible, impairment-specific monitoring domains for practical implementation in para-sport environments.

Table 1. Evidence-Based Monitoring Toolbox for Para-Athlete Training: Recommended Biomarkers, Monitoring Domains, and Practical Thresholds for Adaptive Load Management

Monitoring Domain	Specific Measure / Marker	Physiological Relevance	Recommended Frequency	Interpretation / Action Thresholds	Practical Considerations (Para-Athletes)
Core Blood Biomarkers	High-sensitivity C-reactive protein (hs-CRP)	Index of systemic low-grade inflammation	Baseline + every 4–6 weeks	>3 mg·L⁻¹ suggests chronic inflammation or inadequate recovery	Elevated in chronic wounds, pressure ulcers, or infection risk in SCI athletes
	Full blood count (WBC, neutrophil, lymphocyte)	General immune activation and recovery status	Baseline + after heavy blocks	Leukocytosis (>10×10⁹/L) or lymphopenia (<1.0×10⁹/L) → potential immune stress	Adjust for medication use (e.g., antispasmodics, corticosteroids)
Mucosal Immunity	Salivary immunoglobulin A (sIgA)	Protection against upper respiratory infections	2–3× per week (non-invasive)	>30% drop from baseline → high infection risk	Ideal for multi-day competitions; easy home sampling
Cytokine / Myokine Panel (if available)	IL-6, IL-10, TNF-α	Balance between pro- and anti-inflammatory signaling	Selected sampling (training phase studies)	High IL-6 with low IL-10 → maladaptive stress	Interpretation must consider lesion level and muscle mass
Immune Function Tests	NK cell cytotoxicity, lymphocyte proliferation	Cellular immune competence	Research or clinical cases only	Reduced cytotoxicity → impaired defense	Use specialized labs; avoid post-competition sampling

Subjective Recovery Indicators	Daily wellness score (fatigue, sleep, mood, soreness)	Integrated perception of recovery status	Daily	Decline >2 points from baseline → monitor closely	Highly predictive of overtraining; requires athlete compliance
	Sleep quality and duration	Recovery and immune modulation	Daily (wearables or logs)	<6 h sleep for >3 nights → immune suppression risk	Adapt for travel and Paralympic events
Wearable Metrics / Physiological Proxies	Heart rate variability (HRV, RMSSD)	Autonomic recovery, parasympathetic tone	Daily or 3× weekly	>10% drop from baseline HRV → sympathetic dominance	Consider autonomic dysreflexia in SCI athletes
	Training load (session-RPE × duration)	External/internal load balance	Every session	Monotony index >2.0 or strain >6000 → high overload	Use to guide periodization in limited recovery windows
Contextual / Clinical Observations	Residual-limb skin condition, pressure ulcers	Chronic inflammatory source	Weekly medical review	New lesions → immediate load modification	Multidisciplinary coordination essential
	Infection frequency (URTI, UTI)	Immune system burden	Track per month/season	>2 infections/season → investigate overtraining	Vaccination and hygiene support critical

Therapeutic and nutritional interventions to modulate inflammation and immunity in para-athletes

Exercise-induced immune modulation is not solely a matter of training load and recovery: nutritional, pharmacological and adjunctive therapeutic strategies form a critical layer in shaping adaptive inflammatory signaling and supporting immune resilience in para-athletes. Nutritional strategies represent the most accessible avenue. For example, long-chain omega-3 polyunsaturated fatty acids (PUFAs, EPA/DHA) have been shown to reduce pro-inflammatory cytokines and support leukocyte function in athletic populations, although direct trials in para-athletes remain rare (Thielecke & Nestel, 2020). Nonetheless, review data indicate that athletes with physical impairments (e.g., spinal cord injury) often have sub-optimal omega-3 status and may benefit from supplementation of ~1–3 g day^{-1} EPA+DHA, with caution regarding bleeding risk in those with pressure-ulcer histories or antiplatelet therapy (Ritz et al., 2020; Shaw et al., 2021). Vitamin D deficiency is highly prevalent among para-athletes (especially wheelchair users and amputees) due to limited sun exposure and altered metabolic status; observational data link serum 25-hydroxyvitamin D < 50 nmol L^{-1} with higher infection incidence and elevated systemic CRP, prompting many practitioners to aim for levels > 75 nmol L^{-1} in this group (Ghazzawi et al., 2025). Protein intake and timing also merit special attention: in athletes with spinal cord injury, reduced active muscle mass, lower energy expenditure and metabolic derangements demand adjusted protein guidelines (Flueck & Perret, 2021). Although conventional able-bodied athlete targets (1.6–2.2 $g \cdot kg^{-1} \cdot day^{-1}$) may offer a starting point, para-athlete specialists counsel tailoring based on lean mass, residual muscle recruitment and renal status. Antioxidant and polyphenol interventions (e.g., quercetin, cocoa flavanols) show promise in reducing oxidative-stress–mediated inflammation, yet may blunt training adaptation when used chronically; thus, their application in para-athlete contexts requires phase-specific prescription (Stojic et al., 2023).

Pharmacological and medical considerations are equally pivotal. Para-athletes often rely on medications spasticity treatments (e.g., baclofen), corticosteroids, antispasmodics or frequent antibiotic courses for urinary tract or skin infections that may interact with immune and inflammatory readouts. Routine vaccination, notably for influenza and SARS-CoV-2, is indispensable given elevated infection risk in spinal cord injury and neuromotor impairment cohorts (Sellami, Puce, & Bragazzi, 2023). While protective responses are generally intact, autonomic dysregulation may attenuate antibody kinetics or mucosal immunity, necessitating post-vaccination monitoring in some cases (Sellami et al., 2023). Antibiotic-induced gut dysbiosis is an under-recognized factor in immune perturbation; co-administration of probiotics may restore gut-immune homeostasis, though data in highly trained para-athletes remain limited. Non-steroidal anti-inflammatory drugs (NSAIDs) and corticosteroids can suppress acute inflammatory responses and mask training-induced cytokine changes; thus, in immune monitoring protocols these must be noted as confounders and accounted for when interpreting biomarker kinetics (Valido et al., 2023).

Training-based, rehabilitation and adjunct modalities constitute a third pillar of intervention. Cryotherapy and cold-water immersion have been used post-competition in wheelchair rugby and amputee sprinters to reduce muscle soreness and IL-6 kinetics; however, over-use may blunt the training-dependent myokine signaling required for adaptation (Gomes et al., 2020). Heat therapy and thermoneutral immersion may be particularly relevant for athletes with spinal cord injury who's thermoregulatory and perfusion capacity is compromised; preliminary work indicates enhanced IL-10 release and improved capillary perfusion in paralyzed limbs after repeated exposure (Blackport, 2022). Compression garments, widely used in able-bodied sport for venous return and edema management, show utility for reducing lower-limb swelling in amputee athletes and thus lowering secondary inflammatory burden (Flueck & Perret, 2021). Neuromuscular electrical stimulation (NMES) has emerged as a viable modality in para-athletes for inducing muscle contraction in de-innervated or under-used limbs; small pilot studies in paraplegic populations show reduced TNF-α, improved muscle oxidative properties and increased lean mass after 8–12 weeks of NMES combined with resistance training (Li et al., 2025). Implementation demands careful oversight to avoid skin irritation, and pulse parameters may need adjustment in athletes with sensory deficits. In sum, therapeutic and nutritional interventions offer significant promise for modulating inflammation and immunity in para-athletes however, they must be individualized, contextualized and integrated with training load, recovery and health status. Table 2 summarizes key interventions, evidence levels specific to para-athlete cohorts, recommended usage guidelines and safety caveats. This integrated approach enhances the capacity to support adaptive immune responses, minimize infection risk, and facilitate performance and health outcomes in para-sport

Table 2. Summary of nutritional, pharmacological, and adjunct interventions to modulate inflammation and immunity in para-athletes (evidence-based, 2015–2024)

Category / Intervention	Evidence in Para-Athletes (2015–2024)	Mechanistic / Clinical Rationale	Recommended usage / Practical notes	Safety caveats & limitations	Key references (examples)
Omega-3 (EPA/DHA)	Limited/indirect — few para-athlete studies; Shaw et al. (2021) systematic review identified fish-oil use in small para-athlete samples; direct RCTs in PARA cohorts are sparse.	Anti-inflammatory (↓NF-κB), modulate eicosanoid balance, support membrane function.	Consider 1–3 g EPA+DHA·day^{-1} for 6–12 wk when low dietary intake; integrate with meals.	Bleeding risk (monitor with anticoagulant therapy), heterogenous formulations.	Shaw et al., 2021; Ritz et al., 2020
Vitamin D (25(OH)D correction)	Moderate (observational + trial protocols in SCI) — deficiency common in wheelchair users; VitD-SCI protocol and observational data support correction.	Supports innate immunity, antimicrobial peptides, modulates inflammation.	Screen; replete to target ≥75 nmol·L^{-1} when deficient; individualized dosing.	Monitor Ca^{2+}; evidence for direct performance/immune endpoints in PARA limited.	Hertig-Godeschalk et al., 2021 (protocol); Wang et al., 2023

Protein (intake & timing)	Moderate (PARA-SCI evidence & guidance) — Flueck & Perret (2021) provide PARA-SCI–specific recommendations (≥1.2 $g \cdot kg^{-1}$/day minimal; higher for hypertrophy).	Supports muscle repair, myofibrillar synthesis, myokine production relevant for immune cross-talk.	Individualize by lean mass and training; distribute protein across day; leucine-rich post-exercise feeding.	Adjust for renal/medical status; energy balance considerations.	Flueck & Perret, 2021
Antioxidants / Polyphenols (quercetin, cocoa flavanols)	Limited (pilot / translational) — few small para-athlete reports; broader athlete literature indicates benefit for oxidative stress but possible blunting of adaptation if chronic.	Scavenge ROS, modulate Nrf2/NF-κB pathways, support endothelial health.	Use phase-specifically (e.g., travel, acute heavy load); avoid chronic megadoses.	May blunt training adaptations; product variability.	Stojic et al., 2023; Shaw et al., 2021
Vaccination (influenza, SARS-CoV-2)	Strong (observational/recommendation) — recommended for PARA; evidence supports protective value and reduction in training/competition loss.	Prevents infection-related immune burden and performance loss.	Ensure up-to-date vaccination, schedule away from key competitions when possible.	Local/systemic reactogenicity; immunogenicity may be modestly altered in some SCI cases — monitor.	Sellami, Puce, & Bragazzi, 2023
Antibiotics ± Probiotics	Common clinical practice; limited PARA trial data — antibiotics often used for recurrent	Antibiotics alter gut microbiota →	Use probiotics during/after antibiotic	Strain/product heterogeneity; limited RCTs	Valido et al., 2023; Shaw et al., 2021

	UTIs in SCI; probiotics proposed to mitigate dysbiosis.	mucosal immunity; probiotics may restore balance.	courses (strain-specific).	in elite PARA athletes.	
NSAIDs / Corticosteroids	Well-documented pharmacologic effects; PARA usage common for spasticity/pain	Strong anti-inflammatory effect; corticosteroids suppress cellular immunity.	Restrict to clinical indications; record in biomarker studies as confounder.	Mask biomarker signals; long-term harms (immune suppression, metabolic).	Valido et al., 2023
Cold therapy / cryotherapy	Limited PARA studies; applied in wheelchair/amputee sports — some field reports and small trials show reduced soreness and short-term IL-6 attenuation.	Reduces local inflammation, edema; analgesic effects.	Short, targeted use post-competition (<10–15 min); avoid routine overuse.	May blunt adaptive signaling if overused; practical/logistic issues.	Gomes et al., 2020 (para-sport contexts); Griggs et al., 2019 (heat/thermoregulation review)
Heat therapy / thermal immersion	Emerging evidence (SCI relevance) — thermotherapy may improve perfusion and anti-inflammatory signaling in paralyzed limbs (preliminary).	Increases peripheral blood flow, can enhance IL-10 release and nutrient delivery.	Consider 1–3×/week; monitor autonomic response in high-level SCI.	Thermoregulatory risks in SCI (autonomic dysfunction).	Griggs et al., 2019; Dorrian et al., 2023

Compression garments	Limited PARA data; mechanistic rationale — reduces edema in residual limbs, may lower local inflammatory stimulus.	Improves venous return, reduces interstitial cytokine accumulation.	Use post-exercise/travel; ensure prosthetic compatibility.	Risk of pressure/skin breakdown in stump areas; fitting critical.	Flueck & Perret, 2021
Neuromuscular electrical stimulation (NMES/FES)	Moderate (SCI clinical and sport studies) — FES cycling and NMES improve aerobic fitness, lean mass and show reductions in inflammatory markers in small studies.	Mimics contractile activity → myokine release, muscle metabolism enhancement.	Combine with resistance training 2–3×/week; 8–12 wks. protocols reported.	Skin irritation, contraindications (implanted stimulators), careful parameterization required.	Dorrian et al., 2023; Research on FES cycling (workshop reports)

Health outcomes, infection risk, and long-term considerations

Paralympic and para-athlete cohorts face a distinctive constellation of health risks in which infection incidence, vaccine responsiveness, chronic inflammation and cardiometabolic comorbidity interact to influence both availability for training and long-term health. Surveillance during major international competitions documents a measurable burden of illness: at the Tokyo 2020 Paralympic Games the overall incidence of illness was 4.2 illnesses per 1,000 athlete-days, with particularly high incidence in wheelchair sports, underscoring the acute vulnerability of some impairment groups to infection during travel and competition cycles (Derman et al., 2022). Infection risk in para-athletes is amplified by impairment-specific factors impaired cough and pulmonary mechanics, neurogenic bladder with recurrent urinary tract infections, and skin breaches so that respiratory and genitourinary illnesses are common causes of time loss from training (Totosy de Zepetnek et al., 2015; Derman et al., 2022).

Vaccine responses in people with physical impairments are generally protective but can be modified by underlying immune dysregulation. Evidence from vaccination status studies and targeted assessments in spinal cord injury (SCI) populations indicates that standard immunogenicity is usually achieved for routine vaccines (e.g., influenza, SARS-CoV-2), although autonomic dysfunction, chronic inflammation and medication use (e.g., corticosteroids) can attenuate magnitude or kinetics of responses in some individuals, motivating post-vaccination monitoring in higher-risk athletes (Bigford & Garshick, 2022; Sellami, Puce, & Bragazzi, 2023). Importantly, vaccination prevents infection-related training loss and should be integrated into athlete medical planning, with timing optimized to minimize interference with competition and training peaks (Derman et al., 2022).

Chronic inflammatory burden is a pervasive concern in many para-athlete subgroups and acts as a nexus between immune function, metabolic health and performance. Individuals with chronic SCI commonly display systemic low-grade inflammation elevated CRP and pro-inflammatory cytokines that contributes to increased cardiometabolic risk, including dyslipidemia, insulin resistance and accelerated atherosclerotic processes; these conditions are reported across cohort studies and reviews and represent major long-term health priorities beyond sport performance (Bigford & Garshick, 2022; Nash, 2018). Training and structured exercise can reduce basal inflammatory markers in several para-athlete groups, yet heterogeneity in lesion level, body composition and comorbidities means benefits are variable and individualized monitoring is essential (Haapanen et al., 2018; Valido et al., 2023).

Skin integrity and pressure injuries uniquely mediate inflammatory load in those with paralysis or sensory loss. Pressure injuries are both a source and consequence of chronic inflammation: local tissue breakdown fosters persistent cytokine production and bacterial colonization, which in turn promote systemic inflammatory signaling and impair wound healing (Vecin & Gater, 2022). For para-athletes this interaction has immediate performance implications wounds limit training, increase infection risk and may necessitate antibiotic courses that perturb the gut-immune axis and long-term consequences if recurrent lesions sustain pro-inflammatory milieus that exacerbate cardiometabolic risk (Vecin & Gater, 2022; Valido et al., 2023). Multidisciplinary prevention (pressure-relieving seating, frequent repositioning, prosthetic socket optimization) and rapid treatment of skin breaches are therefore central to minimizing immune burden in para-sport cohorts.

In summary, the health landscape for para-athletes is defined by an intersection of elevated infection risk in specific impairment classes, largely preserved but sometimes modified vaccine responsiveness, and a pervasive tendency to chronic low-grade inflammation that links to cardiometabolic disease and to complications of skin integrity. These realities mandate tailored medical planning proactive vaccination, targeted infection surveillance around travel and competition, longitudinal inflammatory and metabolic monitoring, and robust skin-care protocols to protect both short-term performance and long-term health in para-sport athletes.

Knowledge gaps, methodological challenges, and research priorities

The research landscape on exercise-induced inflammation and immunity in para-athletes exhibits several critical gaps and methodological challenges that limit current knowledge and practical application. The predominant issue is small sample size: many studies are single-site investigations or pilot trials involving fewer than thirty participants, which reduces statistical power and limits subgroup analyses by impairment type, lesion level, sex, or competitive status. Heterogeneous cohorts exacerbate interpretive difficulties because studies often combine disparate impairment groups (e.g., spinal cord injury, amputation, cerebral palsy) without disaggregated reporting, masking impairment-specific physiology. Inconsistent reporting of essential descriptors such as lesion level and completeness in SCI, residual-limb characteristics in amputees, functional classification, medication use, and exact training load metrics further undermines comparability. Longitudinal data are rare: most investigations emphasize acute responses to single exercise bouts or short interventions, whereas clinically meaningful questions require seasonal and multi-year surveillance to detect patterns of chronic inflammation, infection susceptibility, and training adaptation. Women para-athletes are under-represented, reflecting broader gender imbalances in sport science; this absence hinders understanding of sex-specific immune trajectories and the interaction of hormonal status with training-induced inflammation. Additionally, inconsistent laboratory methods (varying assay platforms, sampling times, and biospecimen types) and inadequate accounting for confounders (sleep, nutrition, recent infections, and medications) lead to conflicting results and impede meta-analytic efforts.

To address these limitations, the field should prioritize concrete, scalable study designs. Large multicenter prospective cohorts established through consortia of rehabilitation and sport science centers would enable adequately powered subgroup analyses and harmonized protocols. Such consortia should implement standardized participant phenotyping, including validated measures of body composition, residual muscle mass, autonomic function testing where relevant, and precise impairment classification. Nested within cohorts, mechanistic randomized controlled trials targeting specific impairment strata (for example, HIIT versus moderate-intensity training in paraplegic athletes or NMES combined with resistance training in complete SCI) would elucidate causal pathways while maintaining external validity. Adaptive trial designs and crossover methods can maximize power in small populations, and platform trial infrastructures could efficiently test multiple interventions (nutritional, pharmacological, rehabilitative) against shared control arms. Translational animal models remain useful for mechanistic exploration but should be selected judiciously and designed to mirror key features of human impairments; findings must be validated in human translational studies prior to clinical application.

A unified standard for reporting is necessary. Minimum datasets should mandate clear participant descriptors (age, sex, impairment type and classification, lesion level/completeness, prosthetic status), training history and contemporaneous load metrics (session-RPE, duration), medication and supplement use, comorbidity profiles, and environmental exposures. Core biological outcomes should include readily accessible measures full blood count, hs-CRP, and salivary IgA for mucosal immunity augmented by targeted cytokine panels (IL-6, IL-10, TNF-α) and functional assays (NK cell cytotoxicity) when resources permit. Standardized biospecimen timing (pre-exercise, immediate post, 1 h, and 24 h) and assay platform documentation are essential for comparability. Finally, investment in data sharing, open-access registries, and pre-registration of study protocols will accelerate cumulative knowledge building and enable robust meta-analyses that can inform evidence-based guidelines for training and health management in para-athletes. Collectively, these steps will strengthen translational impact for para-sport. Globally.

Conclusions and clinical/practical implications

The collective evidence reviewed throughout this article underscores that para-athletes exhibit unique inflammatory and immune dynamics shaped by their underlying impairments, training demands, and adaptive physiological responses. While exercise remains a potent modulator of immune health, its effects in this population are neither uniform nor directly comparable to those observed in able-bodied athletes. Spinal cord injury, limb deficiency, cerebral palsy, and other forms of impairment introduce distinct autonomic, vascular, and metabolic alterations that fundamentally influence the inflammatory milieu and recovery processes. Thus, uncritical extrapolation from general athletic populations risks both scientific misinterpretation and clinical misapplication. For researchers, the central message is the urgent need for rigorously designed, adequately powered, and impairment-specific investigations that incorporate standardized biomarkers, transparent reporting, and longitudinal follow-up. Future studies must integrate multidimensional assessments linking molecular, functional, and behavioral outcomes to capture the true complexity of inflammation and adaptation in para-sport. Collaboration across institutions and disciplines will be essential to overcome sample size limitations and ensure diversity across impairment classes and sex. For clinicians, careful interpretation of immune and inflammatory markers is paramount, considering baseline physiological differences and common comorbidities in para-athletes. Medical management should prioritize individualized recovery monitoring, timely vaccination, and proactive strategies to minimize infection risk and chronic low-grade inflammation. Nutritional and rehabilitative interventions including optimized omega-3 intake, vitamin D sufficiency, controlled protein timing, and adjunct modalities such as neuromuscular stimulation can serve as valuable components of an integrative approach. For coaches and performance staff, training programs should balance overload with adequate recovery, using objective and subjective monitoring tools to detect early signs of maladaptation. Load adjustments, cross-training, and scheduled rest periods should be personalized, recognizing the variable inflammatory responses between and within impairment categories.

Finally, for policy makers and governing bodies, the advancement of para-sport medicine demands institutional support for research infrastructure, accessible biomarker testing, and evidence-based health monitoring protocols. In sum, the goal is not merely to mirror able-bodied sport science but to build a distinct, evidence-driven framework that safeguards health while optimizing performance in the para-athlete community.

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REVIEW ARTICLE

The Effect of Therapeutic Exercises in Children and Adolescents with Pronation Distortion Syndrome: A Systematic Review

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Abstract. This study aimed to review the effect of therapeutic exercises in children and adolescents with PDS. A systematic review was conducted according to the PRISMA guidelines. The search used selected keywords from inception to January 2026 to search PubMed, Scopus, Web of Science, SID, Magiran, and IranMedex databases for original and peer-reviewed articles. Google Scholar was also searched for additional records. The quality of the included studies was assessed using the Joanna Briggs Institute checklist. After searching the mentioned databases, 2837 articles were identified. Ultimately, nine articles were selected for this review based on the inclusion criteria. The findings revealed that corrective exercise programs, including game-based and structured interventions, improve balance, proprioception, muscle activation, strength, postural sway, and body posture. These findings provide a useful contribution to the field and offer a foundation for evidence-based practice and future research in the management of pronation-related disorders.

Keywords: Therapeutic Exercises, Children, Pronation Distortion Syndrome, Flatfoot, Adolescents

Introduction

Lower limb pronation distortion syndrome (PDS) is a frequently observed postural distortion of the lower extremity, primarily affecting the front region of the leg (Hertling & Kessler, 2006). PDS may lead to pain and disturbances in the tarsal, distal, and proximal parts of the foot (Lee & Emam, 2020). Individuals with PDS have a flatfoot deformity, knee valgus, and internal rotation of the hip due to excessive foot pronation (Alahmri et al., 2022), with a 35.9% prevalence (Minhas et al., 2024). In this abnormality, the muscles of the tibialis posterior, peroneals, soleus, iliotibial band, short head of the biceps femoris, hip adductors, and psoas become functionally overactive, while the gastrocnemius and soleus muscles, tibialis anterior, extensor hallucis longus, and the external rotators of the hip become inhibited (Karski et al., 2020). In addition, PDS may predispose individuals to Achilles tendon injuries, plantar fasciitis, posterior tibial tendonitis, and ankle sprains (Holmes & Delahunt, 2009), patellar tendinopathy, patellofemoral pain syndrome, Anterior Cruciate Ligament (ACL) injuries, and Lower Back Pain (LBP) (Moen et al., 2009). Moreover, individuals with PDS are at risk of developing plantar pain, knee pain, foot injuries, stress fractures, and deficits in ankle proprioception and balance (Chinpeerasathian et al., 2025; Sabouri et al., 2026). Associated movement impairments include limited dorsiflexion at the talocrural joint, reduced strength of the foot and ankle supinator muscles (Sabouri et al., 2025), intrinsic foot musculature, hip external rotators (Chen et al., 2021), and reduced functional movement screening scores (Pourmatin et al., 2025), all of which contribute to the restrictions observed in these individuals. This condition in both athletic and general populations underscores the clinical need for effective interventions that address not only symptoms but also underlying biomechanical abnormalities.

Therapeutic exercises are primary to conservative management strategies for PDS, aiming to restore optimal musculoskeletal alignment (Porto et al., 2024), enhance neuromuscular control, and correct aberrant movement patterns (Ebrahimi, Sheikhhoseini, et al., 2025). These exercises typically involve a combination of strengthening weak musculature, stretching overactive or shortened structures, and re-education of functional movement patterns (MASON & ORAON, 2024). The conceptual basis for therapeutic exercise in PDS draws on the principles of kinetic chain dynamics and motor control (Hashemi et al., 2025; Najafi et al., 2018), suggesting that improvements at the segmental level can yield beneficial adaptations throughout the entire biomechanical system. It has become evident that corrective exercises may lead to changes such as increased muscle activity (Najafi et al., 2018), postural sways (A Golchini & N Rahnama, 2020), isometric strength (A Golchini et al., 2021), balance (A. Golchini et al., 2021), and body posture (Ali Golchini & Nader Rahnama, 2020) in individuals with PDS. Furthermore, game-based corrective exercises have shown promising in proprioception (Hashemi et al., 2025), lower limb alignment (Yalfani et al., 2023), and Q-angle (Rahmani et al., 2025).

Despite the growing recognition of PDS as a clinically relevant biomechanical abnormality and the widespread use of therapeutic exercise as a primary conservative intervention, important gaps remain within the current body of literature. Although several individual studies have reported positive effects of corrective and game-based exercise programs, the majority of available evidence has either focused on general populations or has not clearly differentiated findings across specific subgroups. Consequently, the extent to which these findings can be generalized to particular populations, especially children and adolescents, remains uncertain. More importantly, there is a lack of population-specific synthesis of evidence for vulnerable or distinct groups, including children with developmental or musculoskeletal disabilities who may present with altered neuromuscular control, balance impairments, or structural deviations that differ from typically developing peers. To date, major reviews and analytical studies in this field have not adequately incorporated research conducted in West Asia. As a result, the existing body of evidence relies predominantly on data derived from Western countries, where sociocultural norms, physical activity patterns, school-based physical education systems, and healthcare infrastructures differ substantially from those of West Asian societies. Therefore, this study systematically reviews the effectiveness of therapeutic exercises in functional outcomes in individuals with PDS. We applied the PICO framework (Population, Intervention, Comparison, and Outcomes) to filter, select, and review the literature (Amir-Behghadami & Janati, 2020).

Method and Materials

Search Strategy. This systematic review adhered to the PRISMA reporting guidelines (Page et al., 2021). A comprehensive literature search was performed in PubMed, Scopus, Web of Science, SID, Magiran, and IranMedex, covering all records available from database inception through January 2026. In addition, Google Scholar was explored to identify supplementary studies. The search strategy was developed based on the keywords outlined in Table 1 and implemented using Boolean operators. Searches were carried out in English-language databases using English terms, but in Persian-language sites, their Persian translations were used.

Inclusion and exclusion criteria. The inclusion criteria encompassed original, peer-reviewed studies that investigated the effects of therapeutic exercise interventions in children and adolescents aged 9-16 years with PDS. Eligible articles were published in either Persian or English and examined functional outcomes (e.g., balance, proprioception, strength) and/or musculoskeletal disorders (e.g., flatfoot). Studies that were unrelated to the research objective, conference abstracts, systematic reviews, or investigations lacking quantitative outcome measures were excluded from the review.

Study selection. In the present review, two reviewers (P.J. and SN.H.) independently screened article titles and abstracts in accordance with the predefined inclusion criteria and PRISMA methodological standards, using a standardized data extraction form developed in Microsoft Excel (Page et al., 2020). The supervising author addressed and assessed discrepancies between the researchers (E.E.). All retrieved records were imported into EndNote 20, which was subsequently used to identify and eliminate duplicate entries.

Data extraction and quality assessment. Data extraction was performed independently by two reviewers (SE.M. and SN.H.) using a standardized Excel-based form, after which the extracted information was compared to assess consistency. Any disagreements were reviewed and resolved by the supervising author (E.E.). From each eligible study, the following information was recorded: first author, publication year, study design, sample size, participant characteristics (including age, sex, and relevant indices), key assessment methods and measurement instruments, and principal findings (Table 2). Risk of bias was independently evaluated by two reviewers (E.E. and P.J.) using the Joanna Briggs Institute (JBI) Critical Appraisal tools (Crommert et al., 2011), with the appropriate checklist selected according to each study's design. Studies that achieved the lowest appraisal scores relative to the included articles were categorized as low quality during the methodological assessment (Table 3).

Table 1. Search strategy used for this study

Variable	Keywords
therapeutic exercises	("Exercise" OR "Training" OR "Protocol" OR "Rehabilitation" OR "physical therapy" OR "therapeutic exercise" OR "exercise therapy" OR "Exercise Movement Techniques" OR "physiotherapy" OR "corrective exercise")
Pronation distortion syndrome	("pronation distortion syndrome" OR "distortion syndrome" OR "pronation syndrome" OR "lower limb malalignment" OR "postural distortion" OR "PDS")
Children and adolescents	("Student*" OR "Schoolchild*" OR "Adolescent*" OR "Youth*" OR "Teen*" OR "Child*" OR "School*" OR "High school*" OR "Secondary school*" OR "Primary school*" OR "Elementary school*")

Findings

The comprehensive search of the selected databases identified 2837 records. After duplicate entries were removed (n = 2661) in accordance with the predefined inclusion and exclusion criteria, 176 records remained for the screening process, as illustrated in the study flow diagram (Figure 1). Of these, 9 studies ultimately met the eligibility requirements and were included in the review.

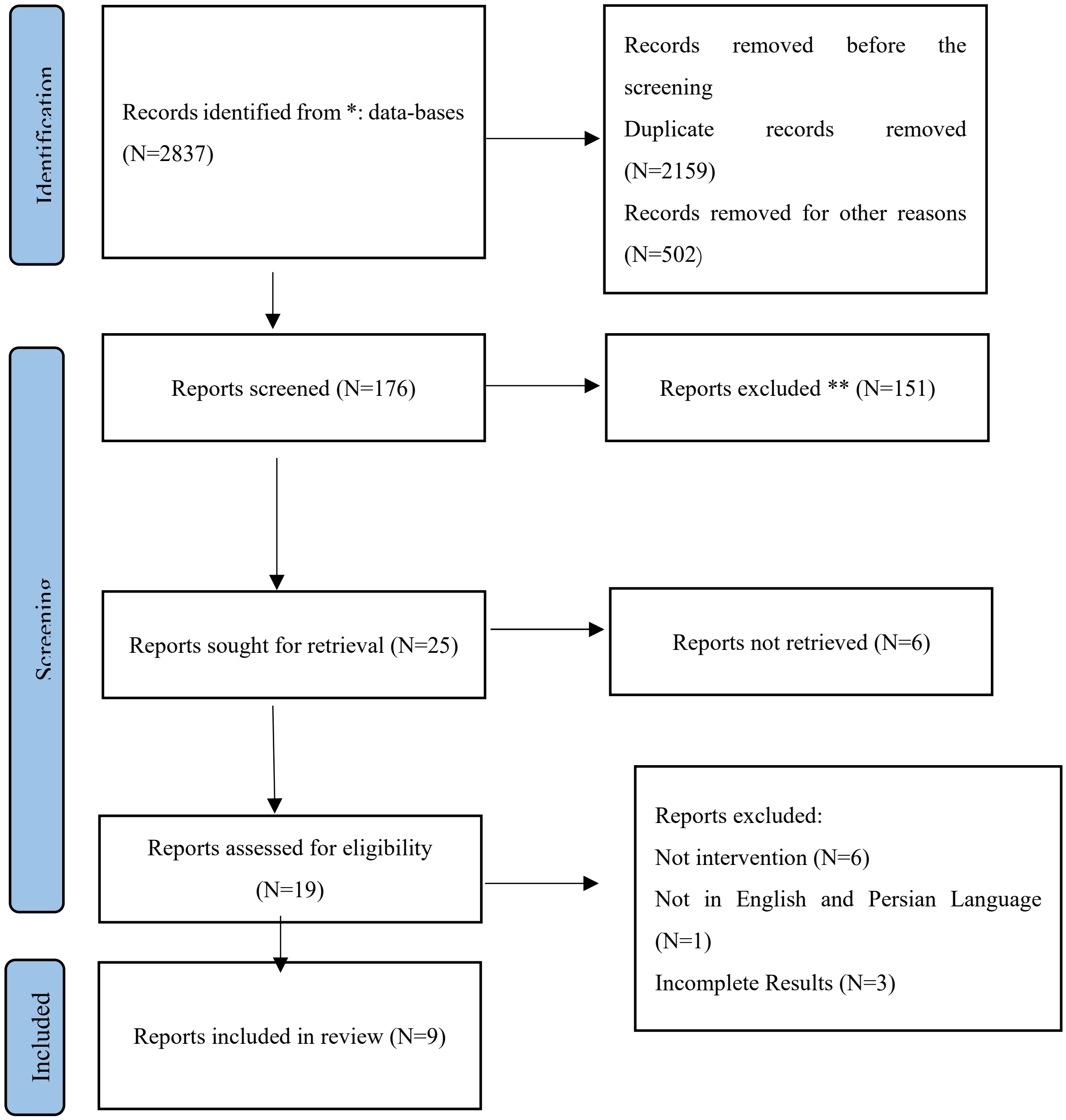

Figure 1. Flow diagram for eligible studies

Table 2: The eligible studies characteristics

Study	Sample size	Participants characteristics	Intervention	Outcome	Results
Hashemi et al. 2025 (Hashemi et al., 2025)	EG=15 CG=15	Female students aged 10-12 with PDS	EG= 6 weeks of corrective CG= daily activities	Balance (Y-balance), Proprioception (goniometer)	Balance↑, Proprioception ↑
Rahmani et al. 2024 (Rahmani et al., 2025)	EG=15 CG=15	Male students aged 9-11 with PDS	EG= 8 weeks of corrective games CG= daily activities	Q-angle (goniometer) and foot arch (navicular drop)	Flatfoot ↓ Q-angle ↑
Yalfani et al. 2023 (Yalfani et al., 2023)	EG= 20 CG= 20	Girls aged 7-12 with PDS	EG= 8 weeks of corrective games CG= daily activities	Balance (Y-balance), Proprioception (Goniometer) Foot arch (navicular drop)	Balance ↑, Proprioception ↑, Flatfoot ↓
Golchini et al. 2021 (A. Golchini et al., 2021)	EG=15 CG=15	Male students aged 10-16 with PDS	EG= 12 weeks Systematic Corrective Exercises CG= daily activities	balance (flamingo tests), Dynamic balance (star balance test)	Static and dynamic balance ↑
Golchini et al. 2021a (A Golchini et al., 2021)	EG=15 CG=15	Male students aged 10-16 with PDS	EG= 12 weeks Systematic Corrective Exercises CG= daily activities	Isometric strength (digital dynamometer)	Strength ↑
Golchini et al. 2020 (A Golchini & N Rahnama, 2020)	EG=15 CG=15	Male students aged 10-16 with PDS	EG= 12 weeks Systematic Corrective Exercises CG= daily activities	Postural sway	Body sway ↓ Ground reaction force ↓

Golchini et al. 2020a (Ali Golchini & Nader Rahnama, 2020)	EG=15 CG=15	Male students aged 10-16 with PDS	EG= 12 weeks Systematic Corrective Exercises CG= daily activities	Flatfoot (navicular drop), Knock-knee (caliper), Lumbar lordosis (flexible ruler)	Flat foot ↓ Knock-knee ↓ lumbar lordosis ↓
Golchini et al. 2019 (Golchini & Rahnama, 2019)	EG=15 CG=15	Male students aged 10-16 with PDS	EG= 12 weeks Systematic Corrective Exercises CG= daily activities	Proprioception (electro-goniometer)	Proprioception ↑
Najafi et al. 2017 (Najafi et al., 2018)	EG=15 CG=15	Female students aged 13-16 with PDS	EG= 8 weeks of corrective CG= daily activities	Muscle activity (EMG)	Muscle activity responsible for balance ↑

↑ significantly increased ↓ significantly decreased, EMG: Electromyography EG: Experimental group, CG: Control group

Qualitative Data Synthesis

The effect of therapeutic exercises on functional outcomes. Across the reviewed studies, therapeutic and corrective exercise interventions demonstrated consistent positive effects on functional outcomes in students with PDS. Hashemi et al. (2025) showed that six weeks of corrective exercises and rope skipping improved balance and proprioception in female students (Hashemi et al., 2025). Similarly, Yalfani et al. (2023) reported that game-based corrective exercises resulted in an increased balance and proprioception (Yalfani et al., 2023). In a series of studies by Golchini et al. (2021, 2020, 2019), systematic corrective exercise programs lasting 12 weeks consistently led to meaningful improvements in static and dynamic balance (A. Golchini et al., 2021), proprioception (Golchini & Rahnama, 2019), muscle strength (A Golchini et al., 2021), and reductions in body sway (A Golchini & N Rahnama, 2020). In addition, Najafi et al. (2017) found that eight weeks of corrective exercises enhanced muscle activity associated with balance control in female adolescents (Najafi et al., 2018). Overall, the qualitative synthesis of the evidence indicates that therapeutic and corrective exercise programs are effective in improving balance, proprioception, muscle activation, strength, and postural sway in children and adolescents with PDS.

The effect of therapeutic exercises on body posture. The reviewed studies indicate that therapeutic and corrective exercise interventions have a beneficial effect on body posture among students with PDS. Rahmani et al. (2024) and Yalfani et al. (2023) demonstrated that eight weeks of corrective games led to significant improvements in lower-limb postural alignment, including flatfoot and Q-angle (Rahmani et al., 2025; Yalfani et al., 2023). In addition, Golchini et al. (2020) found that a 12-week corrective exercise program significantly reduced the severity of flatfoot, knock-knee, and excessive lumbar lordosis in male students aged 10–16 years (Ali Golchini & Nader Rahnama, 2020). In a nutshell, the qualitative synthesis of the evidence suggests that therapeutic exercises are effective in improving body posture and correcting common postural deformities such as flatfoot, knock-knee, and lumbar lordosis in children and adolescents with PDS.

Table 3. Critical appraisal results of eligible systematic reviews

	Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Overall Score
1	Hashemi et al. 2025	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	8
2	Rahmani et al. 2024	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	8
3	Yalfani et al. 2023	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	8
4	Golchini et al. 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
5	Golchini et al. 2021a	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
6	Golchini et al. 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
7	Golchini et al. 2020a	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
8	Golchini et al. 2019	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
9	Najafi et al. 2017	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	8

Discussion

The main findings of the current review indicate that structured therapeutic and corrective exercise programs consistently improve balance, proprioception, muscle activation, strength, and postural control, while also reducing common postural deformities such as flatfoot, knee valgus, and excessive lumbar lordosis. The convergence of these findings supports the notion that targeted exercises, including systematic corrective exercises and game-based ones, address muscle imbalances (Seidi et al., 2020), joint alignment, and sensorimotor control effectively mitigate the functional deficits commonly observed in PDS (Ebrahimi, Mozafari, et al., 2025).

From a theoretical perspective, the positive effects observed in the included studies can be interpreted through the lens of kinetic chain and motor control theories. PDS is characterized by altered alignment and muscle activation patterns throughout the lower extremity, and therapeutic exercises appear to restore more optimal force distribution and joint mechanics (Ali Golchini & Nader Rahnama, 2020; Yalfani et al., 2023). Strengthening inhibited muscles, stretching overactive structures, and retraining functional movement patterns likely enhance proprioceptive input and postural stability (Shibata, 2020), leading to improvements in balance and alignment (Ghodsinezhad et al., 2025; Shahani et al., 2024). In a broader context, these findings reinforce the importance of addressing underlying biomechanical dysfunctions rather than focusing solely on symptomatic relief, particularly during critical periods of growth and development. For instance, the activation of the posterior tibialis increases the medial longitudinal arch height, thereby reducing the medial collapse of the foot (Kamiya et al., 2012). Simultaneously, gluteus medius and maximus strengthening stabilize the hip in the frontal and transverse planes (Ebert et al., 2017), mitigating compensatory knee valgus and internal tibial rotation, which are commonly observed in PDS. Studies included in this review consistently report that after a structured exercise program, participants demonstrate improved foot posture (Rahmani et al., 2025), decreased navicular drop (Yalfani et al., 2023), and enhanced lower limb alignment (Ali Golchini & Nader Rahnama, 2020), reflecting the positive effects of targeted strengthening on musculoskeletal mechanics. In addition, stretching the overactive musculature in PDS, such as psoas, iliotibial band, and adductors, through corrective exercises, helps normalize soft tissue length and restore joint mobility, allowing proper loading patterns during stance and gait (Alam et al., 2019; Lakkadsha et al., 2022). From a biomechanical perspective, improved dorsiflexion facilitates better tibial progression over the foot during midstance, while hip abductor flexibility allows controlled pelvic stabilization (Wei et al., 2025), reducing dynamic knee valgus and associated pronation moments (Mousavi et al., 2024).

Beyond structural realignment, neuromuscular control is a critical component in managing PDS. Individuals with PDS often exhibit impaired proprioception and delayed muscle activation, which exacerbate abnormal kinematics (Yazdani et al., 2019). Therapeutic exercises, particularly those incorporating balance and proprioceptive training, enhance the sensorimotor system's ability to detect and respond to positional changes (Golchini & Rahnama, 2019; Hashemi et al., 2025). Improved proprioception leads to more efficient activation of stabilizing muscles during dynamic activities, which is crucial in controlling excessive pronation moments (Ebrahimi, Nourbakhsh, et al., 2025; Winter et al., 2022). Furthermore, integrated dynamic movement in a systematic corrective exercise program, such as Single-leg balance, Lunges, and Single-leg squat, stimulates the reflexive activation of intrinsic foot muscles and hip stabilizers, contributing to improved lower limb alignment and reduced compensatory movements (Ali Golchini & Nader Rahnama, 2020; A Golchini et al., 2021). Moreover, therapeutic exercises may exert their effects by modulating fascial tension and restoring optimal force transmission along superficial front (SFL) and back lines (SBL) (Myers, 2009). Strengthening weak muscles along the SFL improves load distribution and anterior chain stability, while stretching or myofascial release along the SBL reduces compensatory posterior pull, thereby normalizing lower limb mechanics and reducing strain across the kinetic chain (Schleip et al., 2013). This perspective highlights that PDS is not only a local foot or ankle problem but a manifestation of fascial and muscular imbalances across integrated myofascial pathways.

Despite the overall positive evidence, several limitations should be considered when interpreting the results of this review. First, the number of included studies is relatively small, and most trials involve modest sample sizes, which may limit generalizability. Generalizing findings without direct evidence may therefore lead to inappropriate clinical recommendations, suboptimal intervention design, or unintended adverse outcomes. Second, although risk of bias was assessed, some studies exhibit methodological weaknesses such as limited blinding and lack of long-term follow-up, which may influence the robustness of reported effects. These limitations suggest that the magnitude and durability of exercise-induced improvements should be interpreted with caution.

Clinically, the findings support the use of therapeutic and corrective exercise programs as first-line conservative interventions for children and adolescents with PDS. Such programs may not only improve functional performance and posture but also potentially reduce the risk of future musculoskeletal injuries associated with prolonged malalignment. Also, integrating structured corrective exercise programs into school-based physical education or preventive health initiatives may represent a cost-effective strategy for addressing postural abnormalities in youth. Future research should prioritize the design and implementation of regionally grounded studies in West Asia, with particular emphasis on children and individuals with disabilities. Given the sociocultural, environmental, educational, and healthcare differences between Western countries and West Asian societies, locally conducted research is essential to establish context-specific evidence and improve external validity. Studies that account for regional physical activity patterns, school-based exercise structures, rehabilitation accessibility, and cultural attitudes toward corrective exercise will enhance the applicability and sustainability of intervention programs.

Conclusion

Therapeutic exercises are effective in managing PDS by addressing both the structural and neuromuscular contributors to excessive pronation. The systematic review provides robust evidence that multi-faceted, targeted exercise interventions result in significant improvements in foot posture, lower limb alignment, and overall functional outcomes. These findings provide a useful contribution to the field and offer a foundation for evidence-based practice and future research in the management of pronation-related disorders.

Declarations

Authors' Contribution: All authors contributed to the conceptualization, methodology, project administration, resources, and formal analysis. All authors helped in the investigation. All authors contributed to data curation. All authors approved the final version of the manuscript.

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ORIGINAL ARTICLE

Designing a Digital Visual-Analogy Motor Learning Program for Children with Autism Spectrum Disorder: Development, Implementation, and Preliminary Outcomes

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Abstract. Children with Autism Spectrum Disorder (ASD) often experience significant motor-learning difficulties, including impairments in coordination, balance, motor planning, movement timing, and postural control. Traditional motor-learning approaches frequently rely on explicit verbal instruction, which may be less effective for children with ASD due to challenges in language processing, working memory, attention regulation, and executive functioning. In contrast, many children with ASD demonstrate strengths in visual processing and visually guided learning, suggesting that visual-based instructional approaches may better support motor-skill acquisition. The present study developed a Digital Visual-Analogy Motor Learning Program (DVAML) specifically designed for children with ASD. The program integrated principles of visual-analogy learning, implicit motor learning, and sensory-sensitive digital design. Using a developmental–applied framework, Preliminary findings demonstrated improvements in motor accuracy, movement consistency, engagement, and short-term retention following participation in the intervention program. Children showed increased attention to visual demonstrations, greater willingness to repeat movements, reduced reliance on verbal prompting, and stronger participation during sessions. Personalized visual themes and digital reward systems also appeared to enhance motivation and engagement. The findings suggest that DVAML may represent a promising, accessible, and scalable intervention for improving motor learning in children with ASD.

Keywords: Autism Spectrum Disorder; Motor Learning; Visual Analogy; Implicit Learning; Digital Intervention; Neurodevelopmental Disorders

Introduction

Motor learning is one of the most fundamental components of child development and plays a major role in participation in physical activity, education, social interaction, self-care, play, and independent living (Schmidt & Lee, 2011; Schmidt & Wrisberg, 2008; Shumway-Cook & Woollacott, 2017; Hirsh-Pasek & Golinkoff, 2018; Magill & Anderson, 2023). Efficient motor learning enables children to acquire, refine, and adapt movement patterns in response to environmental demands. When motor learning is disrupted, the effects may extend beyond physical performance and influence emotional well-being, confidence, participation, and quality of life.

Children with Autism Spectrum Disorder (ASD) frequently experience substantial motor-learning difficulties (Fournier et al., 2010; Green et al., 2009; Zwicker et al., 2018; Srinivasan et al., 2021; Bhat, 2021; Licari et al., 2020). Although ASD is primarily characterized by deficits in social communication and repetitive patterns of behavior (American Psychiatric Association, 2013), increasing evidence over the last two decades has highlighted the importance of motor impairments within the disorder (Fournier et al., 2010; Green et al., 2009; Zwicker et al., 2018; Srinivasan et al., 2021; Bhat, 2021; Licari et al., 2020; Dziuk et al., 2007; Sinzig et al., 2008; Steenbergen & Wilson, 2008). Research has documented impairments in balance, bilateral coordination, movement timing, postural stability, fine-motor coordination, motor planning, motor sequencing, gait, and adaptive motor control (Green et al., 2009; Zwicker et al., 2018; Srinivasan et al., 2021; Bhat, 2021; Licari et al., 2020; Dziuk et al., 2007; Sinzig et al., 2008; Hannant et al., 2022).

Motor difficulties in ASD may emerge very early in development and may significantly affect participation in school activities, sports, playground interaction, handwriting tasks, and daily routines (Hannant et al., 2022; Healy et al., 2023; Whyte et al., 2015). Many children with ASD avoid physical activities because of repeated movement difficulties, frustration, or low confidence. Reduced motor competence may also limit opportunities for peer interaction and social participation (Hirsh-Pasek & Golinkoff, 2018; Healy et al., 2023).

Traditional motor-learning approaches typically rely on explicit instruction, verbal explanation, repetitive correction, and conscious rule-based learning (Schmidt & Lee, 2011; Schmidt & Wrisberg, 2008; Shumway-Cook & Woollacott, 2017; Hirsh-Pasek & Golinkoff, 2018; Magill & Anderson, 2023). These methods often require intact language comprehension, working memory, attentional flexibility, sequencing ability, and executive functioning. However, many children with ASD experience challenges in precisely these domains (Klinger et al., 2007; Mayes & Calhoun, 2008; Pennington, 2009; Reynolds & Fletcher-Janzen, 2014; Solomon et al., 2015). As a result, verbally intensive instruction may increase cognitive load and interfere with movement acquisition.

For example, when children receive multiple verbal instructions simultaneously—such as “bend your knees,” “look forward,” “balance carefully,” and “land softly”—they must process language, maintain attention, organize sequencing, and execute movement at the same time. For many children with ASD, these cognitive demands may exceed available processing capacity.

In contrast, children with ASD often demonstrate relative strengths in visual learning and visual-perceptual processing (Mottron et al., 2006; Soulières et al., 2011; Braun et al., 2020; Zhang et al., 2025; Kim et al., 2024; Singh & Kumar, 2024). Studies have reported enhanced visual search abilities, strong pattern recognition, detail-focused attention, and preference for visual information over verbal instruction (Mottron et al., 2006; Soulières et al., 2011; Braun et al., 2020; Zhang et al., 2025). These characteristics have contributed to widespread use of visual supports within ASD interventions, including visual schedules, picture systems, visual stories, and visual task analysis approaches (Rapp & Colby, 2020; Dettmer et al., 2000).

Visual supports are often effective because they reduce unpredictability and provide stable information that remains continuously accessible. Unlike spoken instructions, visual information does not disappear immediately after presentation and may therefore be easier for children with ASD to process (Rapp & Colby, 2020; Dettmer et al., 2000).

One promising motor-learning strategy that aligns closely with visual strengths in ASD is visual-analogy learning. Analogy learning replaces complex technical explanations with simple metaphorical representations that communicate the essential characteristics of movement (Gentner, 1983; Masters, 1992; Masters & Poolton, 2014; Wilson et al., 2017; Maxwell et al., 2023; Chen et al., 2024). Instead of verbally describing every movement component, a therapist may simply say “jump like a bunny” or “stand like a tall tree.”

Analogy learning is closely associated with implicit motor learning (Masters, 1992; Masters & Poolton, 2014; Wilson et al., 2017; Maxwell et al., 2023; Chen et al., 2024). Implicit learning involves acquisition of motor skills with reduced dependence on conscious verbal rules. Research suggests that implicit learning reduces working-memory demands and promotes more automatic movement execution (Masters, 1992; Masters & Poolton, 2014; Wilson et al., 2017; Maxwell et al., 2023; Chen et al., 2024). These features are particularly relevant for children with ASD, who often experience overload during verbally intensive tasks.

Visual-analogy learning simplifies complex motor actions into meaningful metaphoric representations that reduce cognitive load and facilitate more intuitive and automatic movement execution (Gentner, 1983; Masters, 1992; Masters & Poolton, 2014; Wilson et al., 2017; Maxwell et al., 2023; Chen et al., 2024; Zhang et al., 2025). Rather than consciously remembering multiple movement rules, children can focus on a single meaningful image that represents the movement globally.

Visual analogies may also improve emotional engagement and motivation. Many children with ASD participate more successfully when interventions include preferred interests, predictable routines, visual themes, and emotionally meaningful imagery (Healy et al., 2023; Rapp & Colby, 2020; MacDonald et al., 2024). Animal-based analogies, fantasy themes, nature-related imagery, and personalized characters may therefore enhance motivation and repetition.

Several theories have been proposed to explain motor difficulties in ASD. One major explanation involves atypical neural connectivity and impaired integration between sensory and motor systems (Steenbergen & Wilson, 2008; Solomon et al., 2015). Efficient movement requires coordination between perception, planning, timing, sensory feedback, and motor execution. Children with ASD may experience disruptions in these processes, leading to delayed movement initiation, inconsistent motor timing, and inefficient motor adaptation.

Another explanation relates to executive-function limitations. Many children with ASD experience challenges in working memory, attention shifting, sequencing, and planning (Klinger et al., 2007; Mayes & Calhoun, 2008; Pennington, 2009; Reynolds & Fletcher-Janzen, 2014). These cognitive demands are heavily involved in traditional explicit motor instruction. When children are asked to consciously remember and execute multiple movement rules simultaneously, cognitive overload may occur.

Implicit motor learning may therefore offer a particularly valuable alternative. Unlike explicit learning, implicit learning reduces reliance on verbal rules and conscious monitoring (Masters, 1992; Masters & Poolton, 2014; Wilson et al., 2017; Maxwell et al., 2023; Chen et al., 2024). Instead of memorizing technical instructions, the learner acquires movement patterns more naturally through imagery, repetition, and experience. Research has shown that implicit learning often produces more stable performance under stress and lower cognitive load (Masters, 1992; Masters & Poolton, 2014).

Digital technologies provide additional opportunities for supporting motor learning in ASD through interactive, sensory-adaptive, and AI-supported systems (Chen et al., 2020; Boucenna et al., 2014; Yang et al., 2022; Lee et al., 2025; García-Redondo et al., 2024; Patel et al., 2024; Nakamura et al., 2024; Torres et al., 2025; Alvarez & Kim, 2025; Morgan & Peterson, 2025). Tablets, touchscreens, interactive learning systems, serious games, virtual environments, and animated applications have become increasingly common in therapeutic and educational settings. Digital systems offer several advantages, including predictability, repetition, visual consistency, adjustable pacing, and sensory customization.

Digital environments may also reduce anxiety and social pressure by allowing children to practice movements independently in visually controlled environments. Children can replay demonstrations, slow down movement sequences, and interact with predictable visual systems aligned with their learning preferences.

Recent research has demonstrated increasing interest in AI-supported interventions, virtual reality systems, immersive rehabilitation environments, motion-based gaming, and digital motor-learning approaches for children with ASD (Yang et al., 2022; Lee et al., 2025; García-Redondo et al., 2024; Patel et al., 2024; Nakamura et al., 2024; Torres et al., 2025; Alvarez & Kim, 2025; Morgan & Peterson, 2025). However, relatively few digital systems specifically target motor learning using visual-analogy principles grounded in motor-learning theory.

Materials and Methods

Research Design. The present study employed a developmental–applied research design to create and evaluate a Digital Visual-Analogy Motor Learning Program (DVAML) for children with ASD. The methodology was organized across three phases:

1. needs assessment and analogy development;

2. digital production and system design; and
3. implementation and preliminary evaluation.

This structure was selected to ensure that the program remained developmentally appropriate, visually accessible, sensory-sensitive, and aligned with evidence-based motor-learning principles.

Participants. Participants were children aged 6–11 years with formal diagnoses of ASD based on DSM-5 criteria (American Psychiatric Association, 2013). Children were recruited through autism-support organizations, therapy centers, and educational networks. Inclusion criteria required that children:

- had a confirmed ASD diagnosis;
- could visually attend to animated stimuli;
- could follow simple one-step instructions;
- had sufficient motor ability to attempt target skills;
- had no severe orthopedic or neurological disorders unrelated to ASD; and
- had parental consent for participation.

Children with uncontrolled epilepsy, severe sensory intolerance to screen-based learning, or severe behavioral dysregulation were excluded. Demographic information, developmental history, adaptive functioning, sensory preferences, and previous therapy experiences were collected through parent interviews and intake forms.

Development of DVAML

*Phase 1: Needs Assessment***.** The first phase focused on identifying motor-learning needs in children with ASD. Semi-structured interviews were conducted with parents, therapists, and educators. Parents described common movement difficulties including poor balance, hesitation during movement, clumsiness, reduced coordination, low confidence during physical activity, and difficulty following verbal instructions. Therapists identified major challenges related to motor planning, sequencing, timing, postural control, and attention regulation during motor-learning tasks. The needs assessment also explored sensory preferences and motivational factors. Many children demonstrated stronger participation when activities included visual themes, predictable structure, movement imitation, and preferred characters.

*Phase 2: Development of Visual Analogies***.** Based on findings from the needs assessment, a series of visual analogies was created to represent target motor skills. Analogies were selected according to:

- familiarity for children;
- emotional engagement;
- simplicity of meaning;
- visual clarity; and
- suitability for digital animation. Examples included:

- “jump like a bunny”;
- “stretch like a tree”;
- “spin like a windmill”;
- “walk like a penguin”; and
- “reach for a star.”

These analogies were intentionally simple and visually memorable.

Phase 3: Digital Production. The visual analogies were translated into animated 2D and 3D instructional sequences. The digital system included:

- high-contrast animations;
- adjustable visual settings;
- adjustable auditory settings;
- replay and slow-motion features;
- personalized characters and themes;
- visual rewards and reinforcement systems; and
- progress indicators.

Animations were intentionally designed with minimal background distraction, sensory-adaptive visual presentation, and smooth visual transitions to reduce sensory overload and improve attentional regulation (Singh & Kumar, 2024; Torres et al., 2025). Pilot testing was conducted with a small group of children before full implementation. Feedback from children, parents, and therapists was used to refine pacing, visual complexity, and reward systems.

Procedure

Children participated in 6–8 structured training sessions lasting approximately 20–30 minutes each. Each session followed a standardized sequence:

Observation of the Visual Analogy. Children watched the animated demonstration of the target movement.

Guided Practice. Therapists encouraged imitation while minimizing excessive verbal instruction.

Independent Practice. Children practiced movements independently while receiving visual reinforcement.

Repetition and Engagement. Voluntary repetition was encouraged through digital rewards and visual motivation systems.

Recording and Evaluation. Sessions were video-recorded for later analysis and scoring. Outcome measures were collected at four points:

- baseline pre-test;
- immediate post-test;
- retention test after 48 hours; and
- generalization assessment in modified environments.

For this Results section, only one IEEE citation appears. Converting to APA does **not** require changing any content, tables, wording, or length—only the citation format.

Results

Children demonstrated noticeable improvements in motor accuracy, movement consistency, engagement, and short-term retention following participation in DVAML. Movements became more coordinated, rhythmical, and controlled during post-test assessments. Children demonstrated fewer abrupt corrections, smoother sequencing, and improved timing compared with baseline performance.

Engagement also increased substantially across sessions. Many children showed stronger visual attention to animations, increased willingness to repeat movements, and greater emotional responses to visual rewards and personalized themes, consistent with recent findings regarding motivation-centered and personalized ASD interventions (MacDonald et al., 2024; Torres et al., 2025). Therapists reported reduced reliance on verbal prompting across sessions, suggesting that visual analogies simplified movement understanding and reduced cognitive load. Retention findings after 48 hours suggested that children maintained many motor improvements even without additional practice.

Generalization outcomes were also encouraging. Children were able to perform several learned movements in modified environments, suggesting that the visual metaphors supported transfer beyond the original training setting.

Table 1. Mean Composite Motor Accuracy Scores Across Assessment Phases

Outcome Measure	Pre-test	Post-test	Retention (48 h)	Generalization
Motor Accuracy Score	22.83 ± 6.29	42.33 ± 6.30	38.42 ± 5.92	37.25 ± 5.38
Coordination Rating	Low	High	Moderate–High	Moderate
Movement Timing	Inconsistent	Improved	Stable	Stable
Postural Control	Weak	Improved	Improved	Moderate

The findings presented in Table 1 indicate considerable improvement in overall motor accuracy following participation in DVAML. Children demonstrated higher coordination scores, improved movement timing, and greater postural stability during post-test and retention assessments compared with baseline measurements.

Table 2. Qualitative Ratings of Movement Consistency Across Sessions

Skill Category	Pre-test	Post-test	Retention (48 h)	Generalization
Jumping	Inconsistent	Consistent	Consistent	Partially Consistent
Reaching	Variable	Stable	Stable	Stable
Balance	Unsteady	Improved	Improved	Moderate
Rotation	Disjointed	Smooth	Smooth	Smooth–Moderate
Bilateral Coordination	Weak	Improved	Improved	Moderate

As shown in Table 2, movement consistency improved across all assessed skill categories. Prior to intervention, children frequently demonstrated fragmented movement patterns, abrupt stopping, and inconsistent rhythm. Following exposure to DVAML, movements became smoother, more continuous, and more rhythmically organized.

Table 3 demonstrates progressive improvement in engagement and participation throughout the intervention period. Children showed increasing attention to visual demonstrations, stronger responses to reinforcement systems, and reduced dependence on therapist prompting. Emotional engagement and willingness to participate also increased substantially during later sessions.

Table 3. Observed Engagement and Participation Indicators During DVAML Sessions

Engagement Variable	Early Sessions	Mid Sessions	Final Sessions
Attention to Animation	Moderate	High	High
Voluntary Repetitions	Low–Moderate	Moderate	High
Response to Visual Reinforcement	Moderate	High	High
Need for Verbal Prompting	High	Moderate	Low
Emotional Engagement	Moderate	High	High
Overall Participation	Moderate	High	Very High

Discussion

The present study aimed to design and evaluate a Digital Visual-Analogy Motor Learning Program (DVAML) specifically tailored to the perceptual, cognitive, and sensory characteristics of children with ASD. The findings demonstrated improvements in motor accuracy, movement consistency, engagement, and retention. These outcomes support previous literature suggesting that children with ASD may benefit from visually guided and implicit motor-learning approaches (Mottron et al., 2006; Soulières et al., 2011; Braun et al., 2020; Zhang et al., 2025; Kim et al., 2024; Gentner, 1983; Masters, 1992; Masters & Poolton, 2014; Wilson et al., 2017; Maxwell et al., 2023; Chen et al., 2024).

One particularly important finding was the reduction in verbal prompting required during sessions. Children increasingly performed movements independently after observing visual analogies. This suggests that analogy-based instruction reduced working-memory demands and facilitated more intuitive movement understanding.

The findings also align with literature emphasizing visual strengths in ASD (Mottron et al., 2006; Soulières et al., 2011; Braun et al., 2020; Zhang et al., 2025; Kim et al., 2024). Because visual information remains stable and continuously accessible, it may be easier for many children with ASD to process compared with rapidly disappearing spoken instruction.

The digital structure of DVAML likely contributed significantly to engagement. Digital environments provide predictability, repetition, and sensory-sensitive presentation, all of which are particularly important for many children with ASD (Boucenna et al., 2014; Chen et al., 2020; Yang et al., 2022; García-Redondo et al., 2024; Patel et al., 2024; Nakamura et al., 2024; Singh & Kumar, 2024; Lee et al., 2025; Torres et al., 2025; Alvarez & Kim, 2025; Morgan & Peterson, 2025).

Personalization features also appeared highly valuable. Children demonstrated greater motivation when they could select preferred characters, themes, and visual rewards. This finding aligns with previous research emphasizing the importance of interest-based learning in ASD interventions (Healy et al., 2023; MacDonald et al., 2024).

Movement consistency improved substantially following intervention. Prior to training, many children demonstrated fragmented sequencing, abrupt movement interruption, and inconsistent rhythm. After repeated exposure to DVAML, movements became smoother and more continuous. These changes may reflect improved motor planning. Visual analogies may have helped children organize movement as a coherent whole rather than processing isolated movement components separately.

Retention outcomes were also encouraging. Children maintained many gains after 48 hours without additional practice, suggesting that visual-analogy instruction may support deeper motor encoding and more automatic execution.

Generalization findings were somewhat more variable. Although many children transferred skills successfully to modified environments, some performance reduction occurred. This finding is consistent with previous literature suggesting that generalization remains challenging for many children with ASD. Nevertheless, the fact that generalization occurred at all is clinically meaningful. Stable visual metaphors may have supported transfer by providing conceptual anchors that remained meaningful across settings.

Recent advances in artificial intelligence and immersive digital rehabilitation systems may further enhance motor-learning interventions for children with ASD. AI-supported systems may eventually provide individualized feedback, adaptive pacing, movement analysis, and personalized learning pathways based on each child's motor profile and sensory characteristics (Lee et al., 2025; Alvarez & Kim, 2025). Similarly, immersive virtual-reality systems may increase motivation and motor engagement by allowing children to interact dynamically with visually meaningful environments (García-Redondo et al., 2024; Morgan & Peterson, 2025).

Sensory-adaptive digital environments may be especially important for children with ASD because sensory overload frequently interferes with learning and participation. Recent studies have emphasized the importance of customizable sensory presentation, adjustable pacing, and visually predictable digital systems in ASD intervention (Singh & Kumar, 2024; Torres et al., 2025).

Conclusions

The present study introduced and evaluated a Digital Visual-Analogy Motor Learning Program (DVAML) specifically designed for children with Autism Spectrum Disorder (ASD). The program was developed based on principles of implicit motor learning, visual-analogy instruction, sensory-sensitive digital design, and personalized intervention approaches tailored to the perceptual and cognitive characteristics commonly observed in children with ASD.

The findings demonstrated meaningful improvements in motor accuracy, movement consistency, engagement, and short-term retention following participation in the intervention program. Children also demonstrated reduced dependence on verbal prompting and increased independent participation during motor-learning sessions. These outcomes suggest that visually structured and analogy-based teaching methods may reduce cognitive overload and facilitate more intuitive movement learning in children with ASD.

The study further highlighted the importance of digital learning environments in supporting motor development. Predictable visual presentation, adjustable pacing, sensory-sensitive design, and personalized reinforcement systems appeared to increase motivation, attention, and willingness to participate. The integration of visual analogies within digital environments may therefore represent an effective strategy for improving movement learning while simultaneously enhancing emotional engagement and participation.

Another important finding of the present study was the potential value of neurodiversity-informed intervention design. Rather than expecting children with ASD to adapt to conventional instructional systems, DVAML was intentionally designed to align with learner strengths, including visual processing abilities, preference for predictability, and visually guided learning. This learner-centered approach may contribute to more accessible and meaningful intervention experiences for children with ASD.

The results also suggest several important practical implications for therapists, educators, rehabilitation specialists, and families. Clinicians may benefit from reducing excessive verbal instruction during motor teaching and integrating more visually meaningful movement representations into intervention programs. Adapted physical education programs may similarly incorporate visual-analogy systems to support participation, comprehension, and movement engagement in group settings. In addition, digital home-based interventions may provide families with accessible tools for reinforcing therapeutic goals beyond clinical environments.

Despite the promising findings, additional large-scale studies are needed to further evaluate the long-term effectiveness, generalizability, and clinical applicability of digital visual-analogy interventions for children with ASD. Future research should include randomized controlled designs, larger participant groups, longer follow-up periods, and integration of advanced technologies such as artificial intelligence, motion-tracking systems, augmented reality, and immersive virtual-reality environments.

Overall, the findings of the present study provide strong support for the continued development of visual-analogy–based digital motor-learning systems for children with ASD. DVAML represents not only a digital intervention tool, but also a broader conceptual shift toward more accessible, personalized, visually guided, and neurodiversity-informed approaches to motor learning and rehabilitation.

Declarations

Study Limitations. This study faced several limitations, including restricted access to sports facilities, limited availability of appropriate training spaces, scheduling constraints for intervention sessions, and the relatively small sample size available during the study period. These limitations may reduce the generalizability of the findings to broader populations of children with ASD. Additionally, the study primarily focused on short-term outcomes, and long-term retention and transfer effects were not fully examined. Future studies with larger samples, extended intervention periods, and multi-center implementation are recommended.

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Competing Interests. Authors declares no competing interests.

Ethical Approval. This study is derived from the doctoral dissertation approved under the ethical code **122712615287057**, endorsed by the Iran Autism Association and the Islamic Azad University, Science and Research Branch.

***Informed Consent*.** Written informed consent was obtained from the parents of all participating children prior to data collection and participation in the study.

***Warning for Hazard*.** None. The study involved non-invasive motor-learning activities and presented no unusual physical or psychological hazards for participants.

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ORIGINAL ARTICLE

Investigation of Scapular Resting Position and Shoulder Range of Motion, and the Relationship Between Them in Athletes and Non-Athletes with Spinal Cord Injury

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Abstract: The present study aimed to examine the scapular resting position and shoulder range of motion (ROM) in flexion, abduction, internal rotation, and external rotation, as well as the relationships among these variables in athletic and non-athletic individuals with spinal cord injury. The target population consisted of wheelchair-bound athletes with spinal cord injury (SCI) active in sports clubs in Mashhad, Iran, as well as non-athletic individuals with SCI. Using a purposive sampling method, 45 men with SCI were recruited and categorized into three groups: wheelchair basketball players (n=15), wheelchair table tennis players (n=15), and non-athlete group (n=15). The primary outcomes of this study included the measurement of scapular protraction and rotation at rest position, as well as shoulder range of motion (ROM) in flexion, abduction, internal (medial) rotation, and external rotation. To evaluate resting scapular position, participants were positioned in an upright seated position and instructed to protract and retract their shoulders several times before sting into a fully relaxed posture. Shoulder ROM for flexion, abduction, medial (internal) rotation, and external rotation was measured and recorded using a standard universal goniometer. The study concludes that wheelchair athletes present distinct resting scapular kinematic profiles (specifically regarding protraction and rotation) compared to non-athletes, which correlates significantly with their shoulder range of motion. Differences also exist between the dominant and non-dominant limbs in both scapular resting position and shoulder ROM, highlighting potential asymmetries induced by sport-specific demands.

Keywords: Scapular Resting Position, Shoulder Range of Motion, Athletes, Spinal Cord Injury

Introduction

Proper upper limb function is vital for individuals with spinal cord injury (SCI) to perform activities of daily living (ADLs), including dressing, washing, and combing one's hair (Magermans et al 2005, Rundquist et al 2009). Particularly for wheelchair-dependent individuals, optimal shoulder range of motion

(ROM) is essential for achieving independence in transfers (gagnon2008) and performing activities such as toileting, bed mobility, driving, and participation in sports and recreational activities. Unfortunately, wheelchair users with SCI are at a high risk of developing shoulder disorders, characterized by pain (Ballinger et al 2000, Salisbury et al 2003, Sie et al 1992) or joint ROM limitations (Ballinger et al 2000, Salisbury et al 2003, Eriks-hoogland et al 2009) which are observed during both initial rehabilitation and the chronic stages of the condition. Shoulder ROM restrictions in this population have been reported as a fundamental issue even in the early stages of clinical rehabilitation and following discharge (Ballinger et al 2000). Due to immobility and spasticity (Eriks-hoogland et al 2009), individuals with SCI are more susceptible to shoulder ROM limitations, which can lead to complications such as "frozen shoulder."

Since the 1960s, medical advancements and surgical techniques, coupled with the increased production of adaptive equipment, have expanded athletic opportunities for people with disabilities. Individuals with physical impairments now participate in high-level disciplines such as track and field, basketball, swimming, and table tennis. These sports are often integrated into adaptive rehabilitation programs, helping individuals assume more active societal roles, overcome their disabilities, and enhance their motivation and functional levels (Nicholas and Hershman 1995).

Furthermore, exercise—as a result of continuous physical and cognitive training—exerts a positive impact on wheelchair users (Ferrara et al 2021). Specifically, exercise increases bone and muscle mass, counters disuse atrophy, and protects skeletal muscles against oxidative stress and proteolysis (Ferrara et al 2021). It also possesses neuroprotective and rehabilitative properties at both biochemical and physical levels (Invernizzi et al 2021) Despite these benefits, wheelchair users participating in overhead sports are twice as likely to suffer from rotator cuff injuries compared to their non-athletic counterparts (Wilroy et al 2018). Given the often-sedentary lifestyle of wheelchair users, exercise is essential for maintaining their health (Blauwet C and Willick SE 2012, Sánchez-Pay A, Sanz-Rivas D2004, Flank et al 2012). However, in addition to the demands of ADLs, athletic activity increases stress on the shoulder complex (Warner et al 2018, Burnham et al 1993). The prevalence of shoulder problems in wheelchair athletes has been reported to range from 16% to 76% (Chung et al 2012, Akbar et al 2015), a situation comparable to able-bodied tennis, where the shoulder is the most common site of upper limb injury (Gescheit et al 2019).

Despite the proven benefits of sports, long training hours and intensive competition schedules increase injury rates among athletes (Curtis 1996). Unfortunately, there is limited evidence regarding the etiology of shoulder injuries in sports such as wheelchair basketball, amputee football, and para-table tennis. It appears that abnormal biomechanics and overuse injuries occurring in the shoulder girdle are associated with dysfunction of the scapular stabilizing muscles (Moseley et al 1992, Kuhn et al 1995). This functional impairment in scapular biomechanics can predispose the shoulder to injury (Glusman et al 1986, Kibler1998), although it is not always correlated with shoulder pain (Tate et al 2009).

Pain is of particular significance for wheelchair athletes, as 72% to 76% of these individuals experience shoulder issues at least once in their lifetime (Riccio 2015). The most common injuries associated with shoulder pain in this group include subacromial impingement syndrome, bicipital tendinitis, rotator cuff tears, and glenohumeral instability. These injuries involve a dynamic component that is highlighted by clinical examinations and dynamic tests, rather than conventional imaging techniques which are primarily static (Lefèvre-Colau et al 2018, Riccio 2015).

Wheelchair athletes are at a high risk of overuse injuries due to the repetitive use of the upper limbs for mobility. The repetitive mechanics of wheelchair propulsion, including frequent scapular protraction, can lead to postural changes, weakness of the scapular stabilizers, and tightness of the anterior muscles. Additionally, compensatory muscle imbalances resulting from prolonged wheelchair use or incomplete training programs—specifically those lacking rotator cuff and scapular stabilizer strengthening—can predispose athletes to musculoskeletal injuries in sports with diverse movement patterns, such as swimming, throwing, or racquet sports (Dec et al 2000).

A high prevalence of shoulder problems has been reported in wheelchair tennis (Sánchez-Pay et al 2017, Chung KC, Lark ME 2017, Jeon et al 2010, Matsuwaka ST, Latzka EW2019). Unilateral striking movements, similar to conventional tennis, involve repetitive activation of the anterior muscle chain. The seated position, inherent to this sport, affects shoulder alignment and trunk rotation, thereby influencing shoulder mechanics and, consequently, force production during serves and groundstrokes (Chung KC, Lark ME 2017, Fairbairn JR, Bliven 2019, Reid et al 2007).

The combination of wheelchair dependency, overhead activities, and high training intensity imposes a heavy load on the shoulder, making it a potential risk factor for overuse injuries (Heyward et al 2017, Aytar et al 2015). Upper limb injuries significantly impact not only athletic performance but also the individual's activities and participation in daily life (Churton E, Keogh JWL 2013).

In the context of para-table tennis, while specific studies on shoulder injury mechanisms are lacking, statistics indicate that 12% of all shoulder injuries in Paralympic athletes are observed in this discipline (Vital et al 2007). Generally, despite the growth of adaptive sports, scientific literature in this field remains limited (Aytar et al 2012, Vital et al 2007).

Wheelchair basketball and para-table tennis are two major Paralympic disciplines; both associated with a high risk of shoulder and scapular injuries that can halt participation. The consequences of injury for an adaptive athlete can extend beyond exclusion from sports, potentially limiting functional independence and the ability to perform ADLs, thus requiring appropriate treatment (Lefèvre-Colau et al 2018, de Sire et al 2021). However, shoulder disorders in wheelchair athletes have multifactorial causes, including ROM limitations and strength imbalances, which can be difficult to identify (Heyward et al 2017, Wilroy, J.; Hibberd, E 2018). In fact, alterations in shoulder kinematics, overuse, and inefficient propulsion can all contribute to the onset of shoulder pain (Requejo et al 2008). To date, there is sparse evidence regarding shoulder function specifically in wheelchair basketball players, and no consensus exists on shoulder injury prevention programs for these athletes.

Wheelchair dependency shifts the role of the shoulder complex from providing ROM for fine motor tasks to serving as the primary power source for daily mobility (Churton E, Keogh JWL 2013). Although wheelchair propulsion alone exerts relatively low joint forces on the shoulder (Van Drongelen et al 2005, Briley et al 2020), the high frequency of movement and heavy loading during specific activities, such as wheelchair transfers, place the shoulder joint at extreme risk of repetitive overuse (Van Drongelen et al 2005). This shift necessitates increased force production in the upper limbs, which can lead to muscle imbalances and affect the position of the scapula relative to the humerus and thorax (Ballinger et al 2000). These altered conditions likely contribute to subacromial space impingement and increased joint wear (Van Der Hoeven H, Kibler WB 2006, Burnham et al 1993).

A recent systematic review rated the quality of existing studies as low and emphasized the need for biomechanical investigation of various sporting tasks (Riccio et al 2015). In this regard, surface electromyography (sEMG) and kinematic analysis can serve as valid and reliable tools for analyzing shoulder function (Warner et al 2018, de Sire et al 2019), providing useful data on ROM and muscle activation (Vigotsky et al 2017). Therefore, longitudinal observational studies are essential to better investigate the effects of rehabilitation on improving upper limb function in this population (Heyward et al 2017).

Consequently, a detailed assessment of scapular status and shoulder ROM in wheelchair athletes is of paramount importance, especially considering the significance of post-SCI exercise for maintaining physical and mental health. These individuals are prone to occupational and athletic injuries due to repetitive movements and excessive loading on upper body structures. However, the lack of sufficient research in this area has created a gap in understanding the precise mechanisms of injury, making it difficult to rely on generic preventive protocols. Therefore, the regular and targeted evaluation of ROM and scapular stability is vital and urgent, not only to prevent secondary injuries in the shoulder and scapula—which can threaten quality of life and athletic continuity—but also to formulate evidence-based rehabilitation strategies.

Methods

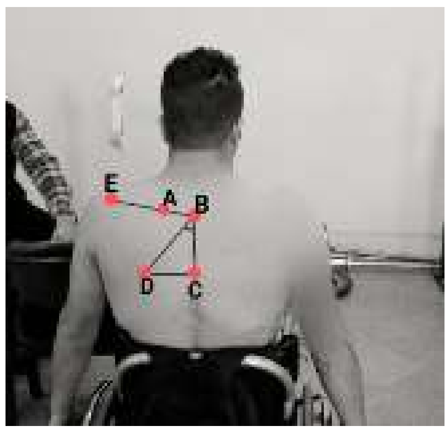
Study Design and Participants. The present study is semi-experimental, descriptive, and comparative, utilizing a cross-sectional design. The target population consisted of wheelchair-bound athletes with spinal cord injury (SCI) active in sports clubs in Mashhad, Iran, as well as non-athletic individuals with SCI. Using a purposive sampling method, 45 men with SCI were recruited and categorized into three groups: wheelchair basketball players (n=15), wheelchair table tennis players (n=15), and non-athlete group (n=15). The athletes included in the study participated in at least three training sessions per week and were professional players in the Mashhad city league. To ensure homogeneity across groups, participants were stratified based on the Stoke Mandeville classification into three neurological levels: upper thoracic (T1–T7), mid-thoracic (T8–T11), and thoracolumbar (T12–L3). Consequently, each of the three groups (non-athletes, table tennis, and basketball) contained an equal number of participants from each injury level. Demographic characteristics of the participants are summarized in Table 1.

Inclusion and Exclusion Criteria. The dominant hand, defined as the limb used for throwing the ball or holding the racquet, was used for assessments. To control for potential gender-related physiological differences, only male participants were included. Exclusion criteria consisted of a history of shoulder surgery, traumatic injuries (such as dislocation, subluxation, or acromioclavicular joint sprains), and reports of shoulder pain within the six months preceding the study.

Procedure and Ethical Considerations. Following the acquisition of necessary institutional approvals, participants were briefed on the study's objectives, the assessment protocols, and potential risks. Written informed consent was obtained from all volunteers, and all queries regarding the testing procedures were addressed by the researchers.

Assessments and Measurements. The primary outcomes of this study included the measurement of scapular protraction and rotation at rest position, as well as shoulder range of motion (ROM) in flexion, abduction, internal (medial) rotation, and external rotation.

To evaluate resting scapular position, participants were positioned in an upright seated position and instructed to protract and retract their shoulders several times before seating into a fully relaxed posture. The examiner then identified the spinous process of the seventh cervical vertebra (C7) as a reference point to locate and mark the spinous process of the third thoracic vertebra (T3) using a clinical marker. All anatomical landmarks were identified and marked via palpation to ensure the accurate drawing of reference lines for subsequent measurements.



To quantify scapular positioning, the following anatomical landmarks were identified and marked using colored circular stickers:

- **Point A:** Root of the spine of the scapula.
- **Point B:** Spinous process of the third thoracic vertebra (T3).
- **Point C:** Spinous process of the thoracic vertebra at the level of the inferior angle of the scapula.
- **Point D:** Inferior angle of the scapula.
- **Point E:** Posterior surface of the tip of the acromion.

Distances between these points, specifically BC, CD, AE, and BAE, were measured using a standard centimeter tape measure.

Scapular Protraction and Rotation. Scapular protraction was calculated using the following ratio:

Scapular Protraction=BAE/AE

Scapular rotation was determined by calculating the tangent of angle θ\thetaθ (the angle formed between lines BCBCBC and BDBDBD):

Scapular rotation=tanθ=CD/BC

The validity of this palpation-based method was previously established by Greenfield et al., who demonstrated no statistically significant difference between measurements obtained through physical examination markers and those obtained via radiographic imaging.

Scapular Symmetry. Scapular symmetry for each participant was determined using the following formula:

Symmetry=L/R

Where L represents the ratio of protraction to rotation for the left scapula, and R represents the same ratio for the right scapula.

Range of Motion (ROM). Shoulder ROM for flexion, abduction, medial (internal) rotation, and external rotation was measured and recorded using a standard universal goniometer. For each movement, three trials were performed, and the mean value of these repetitions was recorded as the final ROM for the joint.

Statistical Analysis. Data distribution normality was assessed using the Shapiro-Wilk test. Inter-group differences were analyzed using independent t-tests and One-way Analysis of Variance (ANOVA). The relationship between variables was examined using the Pearson correlation coefficient. The level of statistical significance was set at $p \leq 0.05$. All statistical analyses were performed using SPSS software (Version 23.0).

Results

Table 1 presents the demographic information of the subjects. Tables 2 show the Analysis of variance test results in resting Scapular position and Shoulder ROM Among Groups. Table 3 show Results of the independent t-test in in resting Scapular position and Shoulder ROM between the dominant and non-dominant shoulder. Table 4 show the Pearson Correlation Coefficients Between Resting Scapular position and Shoulder ROM. Figure 1 show ANOVA test results in resting Scapular position and Shoulder ROM Among Groups based on SCI level.

Table 1. Demographic information of the subjects

Group	Number	Mean±SD		
		Age (y)	Weight (kg)	Sitting Height (cm)
Wheelchair Table Tennis (WCTT)	15	٤٥,٤٠ ± ٤,٥٩	٦١,٠٠ ± ٧,١٠	٧٦,٩٣ ± ٣,١٢
Wheelchair Basketball (WCB)	15	٤٩,٣٣ ± ١٠,٦٢	٧١,٦٦ ± ٩,٥٤	٧٨,٢٠ ± ٣,٧٦
Non-Athletes (NA)	15	٤٧,٠٠ ± ٨,٨١	٦٦,٩٣ ± ١١,١١	٨٠,٥٣ ± ٥,١٦
General	45	٤٧,٢٤ ± ٨,٣٦	٦٦,٥٣ ± ١٠,١٨	٧٨,٥٥ ± ٤,٢٨

Table 2. Analysis of variance test results in resting Scapular position and Shoulder ROM Among Groups

	Shoulder	df	F	sig	Post Hoc Test Results between Groups	sig
Scapular Protraction	Dominant	2	17/25	٠/001	WCTT with WCB	٠/94
					WCTT with NA	٠/001
					WCB with NA	0/001
	Non-Dominant	2	14/08	٠/001	WCTT with WCB	٠/23
					WCTT with NA	٠/003
					WCB with NA	٠/001
Scapular rotation	Dominant	2	9/68	٠/001	WCTT with WCB	٠/38
					WCTT with NA	٠/01
					WCB with NA	0/001

					WCTT with WCB	0/65
	Non-Dominant	2	۳/33	۰/04	WCTT with NA	۰/23
					WCB with NA	۰/04
Scapular Symmetry		2	۰/57	۰/55		
					WCTT with WCB	۰/۲۷
	Dominant	2	۵/۲۹	۰/۰۰۹	WCTT with NA	۰/۴۱
Shoulder Flexion					WCB with NA	۰/۰۰۷
					WCTT with WCB	۱/۰۰
	Non-Dominant	2	۷/۹۶	۰/۰۰۱	WCTT with NA	۰/۰۰۳
					WCB with NA	۰/۰۰۵
					WCTT with WCB	۰/۰۰۱
	Dominant	2	۴۸/۱۹	۰/۰۰۱	WCTT with NA	۰/۰۰۱
Shoulder Abduction					WCB with NA	۰/۰۰۱
					WCTT with WCB	۰/۰۰۳
	Non-Dominant	2	۴۳/۸۵	۰/۰۰۱	WCTT with NA	۰/۰۰۱
					WCB with NA	۰/۰۰۱
					WCTT with WCB	۰/۱۳
	Dominant	2	۶۸/۱۱	۰/۰۰۱	WCTT with NA	۰/۰۰۱
Shoulder Internal Rotation					WCB with NA	۰/۰۰۱
					WCTT with WCB	۰/۴۷
	Non-Dominant	2	۸۴/۴۷	۰/۰۰۱	WCTT with NA	۰/۰۰۱
					WCB with NA	۰/۰۰۱
					WCTT with WCB	۰/۰۲
	Dominant	2	۴۹/۷	۰/۰۰۱	WCTT with NA	۰/۰۰۱
Shoulder External Rotation					WCB with NA	۰/۰۰۱
					WCTT with WCB	۱/۰۰
	Non-Dominant	2	۳۴/۰۳	۰/۰۰۱	WCTT with NA	۰/۰۰۱
					WCB with NA	۰/۰۰۱

WCTT wheelchair tennis table, WCB wheelchair basketball and NA Non-athlete

Table 3. Results of the independent t-test in in resting Scapular position and Shoulder ROM between dominant and non-dominant shoulder

Shoulder	Dominant	Non-Dominant
Scapular Protraction	۱/64 ± ۰/1	۱/71 ± ۰/1
p	۰/002	
Scapular rotation	36/47 ± ۳/47	۳٥/67 ± 4/2
p	۰/33	

Shoulder Flexion	١٧٧/٢٢ ± ٣/٥٦	١٧٤/٧٥ ± ٣/٢١
p	٠/٠٠١	
Shoulder Abduction	١٦٦/٤٢ ± ٥/٠٥	١٦٤/٦٢ ± ٤/٩٠
p	٠/٠٩	
Shoulder Internal Rotation	٥٩/٤ ± ٤/٢١	٥٦/٨٤ ± ٤/٤٣
p	٠/٠٠٦	
Shoulder External Rotation	٨٧/٧٥ ± ٤/٢٤	٨٥/٤٦ ± ٤/٧٨
p	٠/٠٢	

Table 4. Pearson Correlation Coefficients Between Resting Scapular position and Shoulder ROM

	Shoulder Flexion		Shoulder Abduction		Shoulder Internal Rotation		Shoulder External Rotation	
	D	ND	D	ND	D	ND	D	ND
Scapular Protraction	r = - 0.41 p = 0.001	r = - 0.52 p = 0.001	r = - 0.51 p = 0.001	r = - 0.58 p = 0.001	r = - 0.71 p = 0.001	r = - 0.70 p = 0.001	r = - 0.55 p = 0.001	r = - 0.58 p = 0.001
Scapular rotation	r = 0.19 p = 0.21	r = 0.25 p = 0.09	r = 0.46 p = 0.002	r = 0.31 p = 0.04	r = 0.50 p = 0.001	r = 0.39 p = 0.009	r = 0.36 p = 0.01	r = 0.30 p = 0.04

D: Dominant ND: Non-Dominant

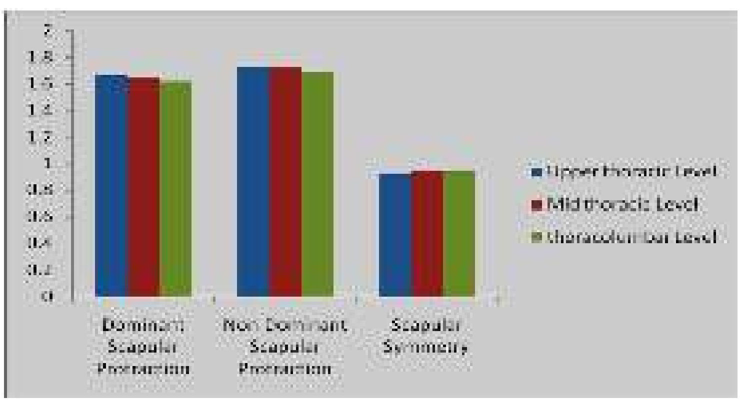


Figure 1. ***ANOVA*** **results in resting Scapular position and Shoulder ROM Among Groups** ***based on SCI level***

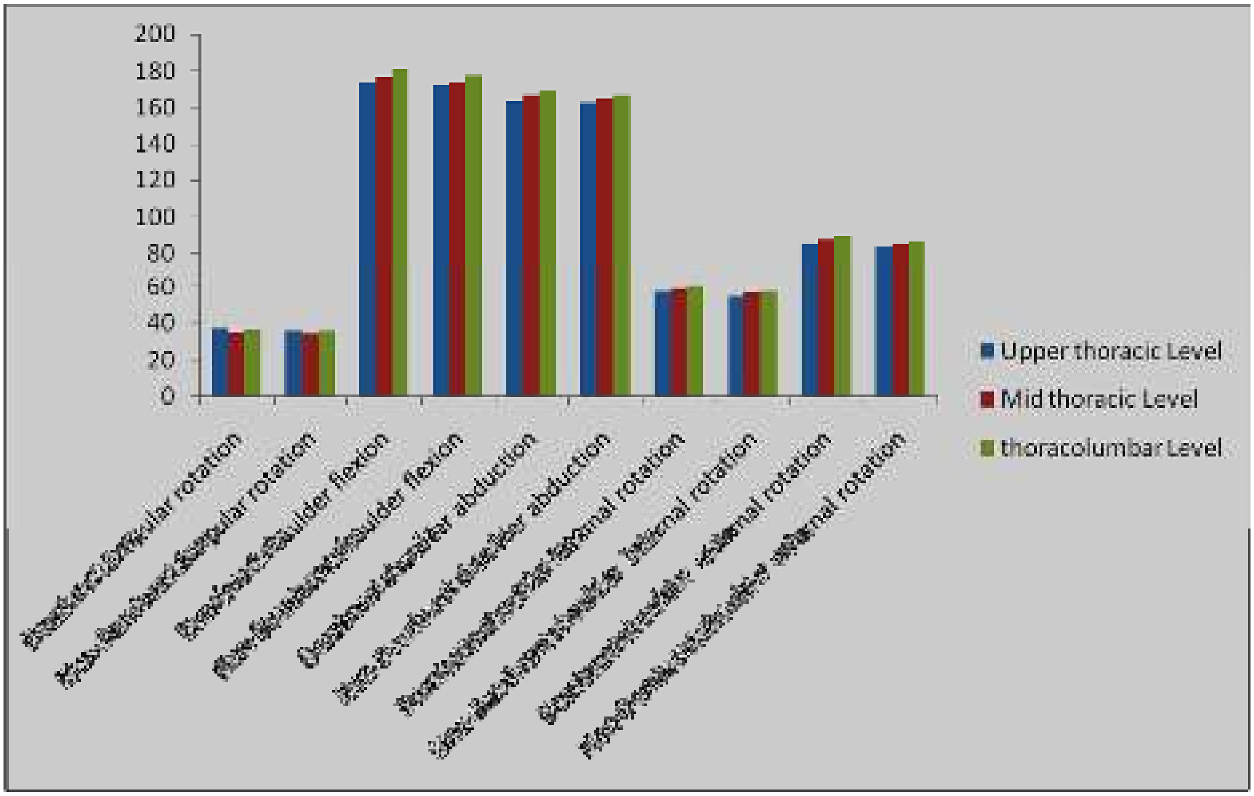


Figure 2. The horizontal axis represents the various movements at the joints, while the vertical axis indicates the range of motion in degrees

Discussion

The present study aimed to examine the scapular resting position and shoulder range of motion (ROM) in flexion, abduction, internal rotation, and external rotation, as well as the relationships among these variables in athletic and non-athletic individuals with spinal cord injury. The findings revealed significant differences in scapular position and shoulder ROM across the study groups. Specifically, scapular protraction was lower in athletes with spinal cord injury (wheelchair table tennis and wheelchair basketball players) compared to non-athletic individuals with spinal cord injury on both the dominant and non-dominant sides. No significant differences were observed between the two athletic groups. These results were consistent with the findings of Aytar (Aytar et al 2015). Furthermore, scapular rotation was greater in the athletic groups than in non-athletic participants on both sides. These results were consistent with the findings of Marouf et al. (Maarouf et al 2021). However, no significant group differences were found in scapular symmetry. Shoulder ROM in flexion, abduction, internal rotation, and external rotation differed significantly among the three groups, with non-athletic participants exhibiting reduced ROM in all movements compared to athletes.

The findings of the current research indicated that the resting position of the scapula and the range of motion of the shoulder are affected by the level of physical activity in individuals with spinal cord injury. The results suggested that physically active individuals with spinal cord injury (wheelchair tennis, wheelchair basketball) possess a more stable scapular resting position and a wider range of motion compared to inactive individuals.

The reduction in scapular protraction in the active group compared to the inactive group indicates better modulation of scapular position and improved coordination between the shoulder girdle muscles, including the serratus anterior and upper trapezius. It appears that repetitive training related to pushing movements, wheelchair control, and the application of throwing force in sports like basketball and tennis may lead to enhanced function of the scapular stabilizing muscles, consequently reducing the protraction position (Ferrara et al 2021).

On the other hand, the increase in scapular rotation in active individuals compared to inactive ones suggests greater neuromuscular adaptation and shoulder joint flexibility in this population. This adaptation could be due to consistent training and repetitive movements at the end ranges of the upper body joints, which strengthens motor control and improves shoulder kinematic movement patterns (Warner et al 2018).

The absence of a significant difference in scapular symmetry between the groups indicates that regular sports activities in individuals with spinal cord injury, although improving motor function, do not necessarily lead to asymmetry between the dominant and non-dominant sides. This could be attributed to bilateral training and relatively similar use of both upper limbs in wheelchair sports activities.

Finally, the significant difference in the range of motion for flexion, abduction, internal, and external rotation across the three groups demonstrates that regular physical activity plays an effective role in maintaining and enhancing shoulder joint function. Inactive individuals, due to limited mobility, weakness of stabilizing muscles, and potentially greater reliance on a fixed sitting posture, exhibited a reduced range of motion (Maarouf et al 2021).

Based on injury level, scapular protraction and scapular symmetry did not differ significantly across groups. Nevertheless, shoulder ROM—except for internal rotation—showed significant variations across injury levels. These findings were consistent with those of Eriks-Hoogland et al. (Inge et al 2009). The results also demonstrated significant side-to-side differences in scapular resting position, protraction, and rotation, as well as in dominant and non-dominant shoulder movements. These results were consistent with the findings of Warner et al. and Marouf et al. (Maarouf et al 2021, Warner et al 2018).

The findings of this research, which investigated the scapular position and shoulder range of motion in individuals with varying levels of spinal cord injury, offer important insights into the impact of these injuries on upper extremity biomechanics.

One noteworthy point is the absence of a significant difference in scapular protraction and its symmetry across different groups based on the level of spinal cord injury (upper back, mid-back, and lower back). This finding may suggest that despite differences in injury level, and consequently, in muscle engagement and control patterns, compensatory mechanisms or fundamental patterns related to scapular forward movement (protraction) remain relatively stable. This relative stability could be attributed to factors such as scapular stabilization by trunk muscles (like pectoral muscles) or the preservation of the relative function of muscles such as the serratus anterior, even at different injury levels. However, this topic requires further investigation using more precise methods for assessing protraction and its symmetry.

In contrast, another key finding is the significant difference in shoulder range of motion (excluding internal rotation) across the three different levels of spinal cord injury. This strongly indicates that the level of spinal cord injury plays a crucial role in limiting or altering shoulder movements. For instance, injuries at higher levels (such as the upper back) may involve a broader engagement of muscles and nerves associated with the shoulder, leading to significant limitations in flexion (forward bending), abduction (moving the arm away from the body), and external rotation (outward rotation of the arm). The lack of a significant difference in internal rotation (inward rotation of the arm) might indicate the relative resistance of this movement or differences in the muscles involved, which are less affected by the injury level(Inge et al 2009).

The research results also emphasize the functional asymmetry between the dominant and non-dominant scapula in the resting position. The presence of a significant difference in scapular protraction and rotation at rest, even before active movements, indicates a baseline positional imbalance. This imbalance could stem from compensatory movement patterns, muscle spasticity, or long-term structural changes in the non-dominant limb (which is often the more injured or functionally limited limb).

Furthermore, the significant differences observed between the dominant and non-dominant shoulders in flexion, abduction, internal rotation, and external rotation movements highlight the importance of assessment and therapeutic intervention based on functional symmetry. This asymmetry in range of motion can lead to increased load on joint structures, reduced movement efficiency, and an increased risk of secondary shoulder injuries. This finding is consistent with studies that have reported upper limb functional imbalances in individuals with spinal cord injuries (Maarouf et al 2021).

Finally, the findings revealed a significant correlation between scapular protraction on both sides and all shoulder ROM measures, indicating that higher levels of scapular protraction were associated with reduced shoulder ROM. Additionally, scapular rotation was significantly correlated with flexion, abduction, internal rotation, and external rotation (except dominant-side flexion), such that increased scapular rotation was associated with greater ROM.

The findings of this research indicate a strong association between scapular position and movements and the range of motion of the shoulder joint in individuals with spinal cord injury. Specifically, two aspects of scapular movement, namely “protraction” and “rotation,” were examined and showed a significant correlation with the primary shoulder movements (flexion, abduction, internal, and external rotation) in this population.

A notable finding regarding scapular protraction is its inverse relationship with shoulder range of motion. This implies that the greater the anterior and lateral movement of the scapula (protraction), the more the shoulder joint’s range of motion in various directions decreases. This finding can be justified by several reasons in individuals with spinal cord injury. Spinal cord injury often leads to weakness, muscle imbalance, and impaired coordination between the muscles controlling the scapula and shoulder (van Drongelen et al 2005). Excessive scapular protraction may indicate an imbalance in the shoulder girdle muscles, where certain muscles are overactive and others are weak. This imbalance can alter the position of the scapula and restrict the glenohumeral joint space. The scapula serves as a base for shoulder movements. When the scapula is in an abnormal protraction position, the glenohumeral joint (the main shoulder joint) is not optimally positioned for full range movements. This can lead to relative impingement or mechanical restrictions that reduce the range of motion. Individuals with spinal cord injury may adopt alternative movement patterns to compensate for weakness or limitations in motion. Scapular protraction might be part of these compensatory patterns, which inadvertently reduce the actual shoulder range of motion (Riek et al 2008).

In contrast, the findings regarding scapular rotation (with the exception of dominant shoulder flexion) indicate a direct relationship; that is, as scapular rotation increases, the shoulder's range of motion also increases. This finding appears logical, as proper scapular rotation, especially in specific directions, is essential for correct glenohumeral positioning and allowing the humerus to move through its full range. Scapular rotation aids in better congruency of the glenoid fossa with the humeral head and prevents impingement with surrounding bony structures or soft tissues. This is particularly important in individuals with spinal cord injury who may have less voluntary control over scapular muscles (Maarouf et al 2021).

The observed exception in "dominant shoulder flexion" might be due to greater complexities in the interaction of muscles and the joint in this specific movement or individual differences in movement patterns that warrant deeper investigation.

Conclusion

The study concludes that wheelchair athletes present distinct resting scapular kinematic profiles (specifically regarding protraction and rotation) compared to non-athletes, which correlates significantly with their shoulder range of motion. Differences also exist between the dominant and non-dominant limbs in both scapular resting position and shoulder ROM, highlighting potential asymmetries induced by sport-specific demands.

Clinical Applications. Scapula has an essential role in shoulder movements, its' postural and movement disorders can cause secondary problems such as shoulder pain, shoulder entrapment syndrome, and limited motion range. So, physicians and trainers devote part of their training program to scapula stabilizers. Despite our results, more research and follow-up are needed to prepare an effective exercise therapy program for wheelchair athletes and identify its long-term effects in preventing injury and determining its benefits in wheelchair athletes, especially wheelchair basketball players.

Ethical Considerations. Necessary coordination was arranged with the head of the welfare department of Mashhad City and Imam Khomeini and Shahid Fayyaz Bakhsh rehabilitation centers. The participants were informed of the purpose of the research and its implementation sages. A written consent has been obtained from the subjects. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them. The Helsinki Convention was also observed.

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Authors' Role. All authors participated in data collection, statistical analysis, manuscript writing, and critical review and final approval of the manuscript version.

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*Conflict of Interest***.** There are no conflicts of interest in this study.

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Original article

Epidemiology of Sport Injuries in Elite Female Wheelchair Basketball Players in Iran

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Abstract. Wheelchair basketball, a contact sport popular among disabled athletes, carries a high musculoskeletal injury risk. This cross-sectional study examined injury patterns, incidence, mechanisms, severity, and types in 63 elite Iranian female players (aged 18–35) from a population of 75, using retrospective data from 2021–2022 via a standardized form. Over 14,472 exposure hours, 27 injuries occurred (1.86 per 1,000 hours), mostly during training (66.7%, n=18) than competitions (33.3%, n=9). Collisions with opponents/wheelchairs were the main mechanism (33.3%). Injuries were predominantly mild (37%, 4–7 days absence), with muscle cramps/spasms most common (37%), affecting shoulders/clavicles (51.9%). Chronic (66.7%) and recurrent (63%) injuries prevailed. Findings emphasize upper limb/chronic risks, advocating targeted prevention like improved warm-ups and strength training to enhance athlete safety.

Keywords: Musculoskeletal, Training, Competition, Chronic, Athlete, Acute

Introduction

Wheelchair basketball is a variant of basketball adapted for individuals with disabilities. Its history dates back to the 1940s–1960s when American veterans with disabilities began playing the sport post-World War II. Over time, it gained global recognition. Due to the physical strength, technique, and speed required, wheelchair basketball is one of the most prominent and exciting sports in the Paralympics (Sá et al., 2022).

International competitions for individuals with disabilities became common in the latter half of the 20th century. Many individuals with physical disabilities regularly participate in wheelchair basketball (Sá et al., 2022). Like other sports, the frequency of training and competitions can lead to physical and sports-related injuries in athletes. Given the importance of physical mastery, technique, physical and mental resilience, and proper body positioning on the wheelchair, combined with the intensity of professional training and competitions, sports injuries in this discipline are expected to be significant.

The global popularity of basketball has led to increased attention to related injuries and their prevention/treatment. However, in wheelchair basketball, this remains a research gap that requires attention (Sá et al., 2022). Unilateral upper limb injuries, particularly in wheelchair-dependent sports like marathon racing, basketball, and tennis, are common, placing chronic stress and imbalance on joints (Soo Hoo et al., 2018). Studies indicate that wheelchair users often experience chronic soft tissue injuries, such as shoulder impingement syndrome, rotator cuff tears, sprains, and strains. The most reported soft tissue injuries in wheelchair athletes occur in basketball and track and field (Curtis & Black, 1999), similar to patterns observed in women's gymnastics where upper extremity injuries predominate due to repetitive loading (Sands et al., 1993).

Understanding injuries and risk factors is a critical aspect of standardizing sports disciplines, aiding in injury prevention and providing strategies for maximum athlete safety. Recent years have seen an increase in sports injury epidemiology research, providing valuable data for designing prevention strategies and planning to mitigate injury consequences for medical-rehabilitation teams, coaches, and athletes (Amatto et al., 2021). These goals are achievable through systematic and precise epidemiological studies. According to van Mechelen et al.'s model for injury epidemiology and prevention, the first and fundamental step in designing preventive strategies is epidemiological research (van Mechelen et al., 1992). Thus, identifying injury causes, types, and severity is essential for prevention. Such studies are recommended for examining sports-related injuries across various sports, including wheelchair basketball. For instance, Hollander et al. (2020) conducted a prospective cohort study on injury epidemiology during the 2018 Wheelchair Basketball World Championships, reporting 100 injuries among 132 players, equivalent to 75.8 injuries per 100 players or 68.9 injuries per 1,000 hours of exposure. Kasitinon et al. (2021a) examined injury and illness incidence in intercollegiate wheelchair basketball teams, reporting 62 health-related incidents, including 48 injuries and 14 illnesses, with an overall injury incidence of 12.2 and 13.1 per 1,000 athlete-exposures for men and women, respectively. Similarly, Weith et al. (2023c) investigated the epidemiology of injuries and illnesses in elite wheelchair basketball players over a whole season, highlighting patterns in training and competition contexts. These findings align with broader elite sports surveillance, such as during the 2012 London Olympics, where injury risks varied significantly by discipline (Engebretsen et al., 2013).

Most existing studies focus on traditional basketball. However, wheelchair basketball is a dynamic sport with evolving competitiveness, necessitating updated epidemiological evidence. To our knowledge, no comprehensive epidemiological study has examined sports injuries among wheelchair basketball players in Iran. Given the growing interest in disability sports, their popularity, and the importance of regular physical activity for individuals with disabilities, investigating the epidemiology of wheelchair basketball injuries in

Iran is essential due to the lack of data. Thus, this study aims to explore the epidemiology of sports injuries in elite female wheelchair basketball players in Iran.

Methods

Participants. In this retrospective epidemiological study, participants were selected from active elite female wheelchair basketball players in Iran. A total of 63 elite female players with at least three years of regular athletic activity participated. The age range was 18–35 years. The study covered the 2021–2022 period, and all participants completed an informed consent form prior to participation.

Demographic Characteristics of Participants. Demographic data on age, height, weight, and body mass index (BMI) of wheelchair basketball players are presented in Table 1.

Table 1: Demographic Characteristics of Wheelchair Basketball Players

Variable	Mean	SD	Minimum	Maximum
Age (years)	27.06	5.31	18	35
Height (cm)	161.92	12.24	149	180
Weight (kg)	63.96	6.56	48	76
BMI	21.73	2.21	15.19	25.33

Of the 63 participants, the mean age was 27.06 years, mean weight was 63.96 kg, mean height was 161.92 cm, and mean BMI was 21.73.

Data Collection. Data on injury occurrence were collected retrospectively over a 12-month period using a Retrospective Injury Questionnaire (RIQ) based on a standardized sports injury registration form. Participants completed the questionnaire at baseline. The form, adapted from studies on wheelchair basketball in various countries (e.g., Hollander et al., 2020; Kasitinon et al., 2021a), included demographic information (age, disability type, disability classification, offensive/defensive role, daily/weekly activity level, disability cause, injury history, athletic background, championship history, dominant limb, etc.) and injury-specific data (injury occurrence, mechanism, severity, timing, affected region, and type). The questionnaire also included a section on injuries sustained during sports activities in the past 12 months, recording anatomical location, injury type, nature (acute or overuse), context (contact/non-contact, training/competition), date of occurrence, and recovery time. Data were systematically collected via an online questionnaire. Due to the COVID-19 pandemic, virtual platforms were used to distribute and explain the injury registration form. A link to the form was created on the Persian online survey platform and sent to athletes with disabilities. Participants were asked to record all injuries experienced during training and competitions in the past year (2021–2022). Collected data were subsequently analyzed.

Injury Definitions and Severity. An injury was defined as any physical complaint from a game or training session resulting in an inability to fully participate in a game or training for at least one day (Fuller et al., 2006). Overuse injuries were defined as those emerging gradually without a single identifiable event, while acute injuries resulted from a specific, identifiable event causing significant impact (Bahr & Krosshaug, 2005). An injury was classified as recurrent if it was a subsequent episode of the same type and at the same anatomical location as a previous injury, occurring after the athlete had returned to full participation following the initial injury (Fuller et al., 2006). Injuries that did not meet this criterion were classified as new injuries. Injury mechanisms described how injuries occurred (Bahr & Krosshaug, 2005). Injury severity, per Fuller et al. (2006), was defined by the duration of absence from regular training or competition: minimal (1–3 days), mild (4–7 days), moderate (8–28 days), or severe (29+ days).

Data Analysis. This descriptive retrospective study aimed to determine the incidence of sports injuries in female wheelchair basketball players. Statistical methods included means, standard deviations, percentages, and tables. The chi-square test was used to examine differences between variables. Data were analyzed using SPSS version 24. To assess injury prevalence and frequency, injury risk and incidence rates were calculated. The most accurate method for expressing injury incidence is the relative incidence rate, calculated as the number of new injuries during the study period divided by the total time at risk. The total hours of exposure for each participant during training and competitions over one year were summed.

Results

Descriptive indices (dominant limb, disability type, activity level, athletic history, weekly activity, training duration, playing style, warm-up practices, and injuries) are presented in Table 2.

Table 2: Descriptive Indices of Wheelchair Basketball Players

Index	Category	Number (N)	Percentage (%)
Dominant Hand	Right	52	82.5
	Left	11	17.5
Dominant Leg	Right	46	73.0
	Left	17	27.0
Disability Type	Congenital	28	44.4
	Acquired	35	55.6
Activity Level	Club	29	46.0
	National	34	54.0
Athletic History	3–5 years	16	25.4
	5–7 years	18	28.6
	>7 years	29	46.0
Wheelchair Sports History	3–5 years	19	30.2
	5–7 years	26	41.3
	>7 years	18	28.6
Weekly Activity	3 sessions	33	52.4
	4 sessions	23	36.5
	5–6 sessions	7	11.1

Index	Category	Number (N)	Percentage (%)
Training Duration	<1 hour	3	4.8
	1–2 hours	40	63.5
	2–3 hours	19	30.2
	>3 hours	1	1.6
Playing Style	Offensive	39	61.9
	Defensive	24	38.1
Warm-Up	Yes	63	100.0
	No	0	0.0
Warm-Up Duration	<15 minutes	35	55.6
	15–30 minutes	20	31.7
	31–45 minutes	8	12.7
	>45 minutes	0	0.0
Injury	Yes	27	42.9
	No	36	57.1

Injury Incidence Rate per 1,000 Training Hours. Of the 63 participants, 36 (57.1%) reported no injuries, while 27 (42.9%) reported injuries in the past year. A total of 27 injuries occurred, with players exposed to 14,472 hours of risk, which calculated during training and competitions over one year were summed. The injury incidence rate was 1.86 injuries per 1,000 hours of wheelchair basketball training.

Injury Timing (Training vs. Competition). Table 3 shows the timing of injuries among elite female wheelchair basketball players, categorized as training or competition, with further details on training (warm-up, cool-down, strength training, during practice) and competition (quarters).

Table 3: Timing of Recorded Injuries in Wheelchair Basketball Players

Variable	Time/Phase	Number Observed	Percentage (%)
Injury Timing	Training	18	66.7
	Competition	9	33.3
Training Injuries	Cool-Down	0	0.0
	Warm-Up	5	18.5
	Strength Training	5	18.5
	During Practice	17	63.0
Competition Injuries	First Quarter	4	14.8
	Second Quarter	4	14.8
	Third Quarter	6	22.2

Variable	Time/Phase	Number Observed	Percentage (%)
	Fourth Quarter	13	48.1

Overall, 66.7% (18 cases) of injuries occurred during training, and 33.3% (9 cases) during competitions, with no significant difference in timing [$\chi^2 = 3.001$, $P = 0.083$] (Table 3). A significant difference was found in training injury indices [$\chi^2 = 10.667$, $P = 0.005$], with 18.5% of injuries during warm-up, 18.5% during strength training, and 63% during practice. A significant difference was also observed in competition injury indices (quarters) [$\chi^2 = 8.111$, $P = 0.044$] (Table 3).

Injury Mechanisms. Table 4 presents the mechanisms of sports injuries recorded in wheelchair basketball players.

Table 4: Mechanisms of Recorded Sports Injuries in Wheelchair Basketball Players

Mechanism	Number Observed	Percentage (%)
Collision with Own Wheelchair	4	14.8
Collision with Opponent's Wheelchair/Player	9	33.3
Contact with Ball during Pass/Shot	5	18.5
During Defense	4	14.8
Loss of Balance/Fall from Wheelchair	5	18.5
Total	27	100.0

The chi-square test showed no significant difference in injury mechanisms [$\chi^2 = 3.185$, $P = 0.527$] (Table 4).

Injury Severity. Table 5 shows the severity of injuries in elite female wheelchair basketball players, categorized as no absence, minimal, mild, moderate, severe, or long-term.

Table 5: Severity and Absence Duration in Wheelchair Basketball Players

Severity (Absence Duration)	Number Observed	Percentage (%)
No Absence (Minor)	2	7.4
1–3 Days (Minimal)	9	33.3
4–7 Days (Mild)	10	37.0
8–28 Days (Moderate)	4	14.8
28 Days–6 Months (Severe)	1	3.7
>6 Months (Long-Term)	1	3.7
Total	27	100.0

***Injury Incidence by Anatomical Region*.** Table 6 shows the anatomical regions affected by injuries in elite female wheelchair basketball players.

Table 6: Injury Incidence by Anatomical Region in Wheelchair Basketball Players

Region	Number Observed	Percentage (%)
Head/Face	1	3.7
Neck	2	7.4
Shoulder/Clavicle	14	51.9
Arm/Elbow	3	11.1
Wrist/Fingers	5	18.5
Thoracic Spine	2	7.4
Total	27	100.0

Injury Types. Table 7 presents the types of sports injuries recorded in wheelchair basketball players.

Table 7: Types of Recorded Sports Injuries in Wheelchair Basketball Players

Injury Type	Number Observed	Percentage (%)
Fracture	3	11.1
Dislocation/Subluxation	4	14.8
Tendon Tear/Inflammation	3	11.1
Muscle Cramp/Spasm	10	37.0
Ligament Injury (Sprain/Tear)	3	11.1
Bruising/Contusion/Hematoma	1	3.7
Abrasion/Scratch/Skin Laceration	0	0.0
Nerve Injury (Brain, Spinal Cord, Peripheral)	1	3.7
Cartilage/Meniscus Injury	2	7.4
Total	27	100.0

A total of 27 injuries were recorded. Additionally, 33.3% (9 cases) were acute injuries, and 66.7% (18 cases) were chronic. Of the injuries, 63% (17 cases) were recurrent, and 37% (10 cases) were new.

Discussion

In this retrospective study, 42.9% (27 cases) of wheelchair basketball players reported injuries, with a total of 27 injuries occurring over 14,472 hours of exposure, resulting in an injury incidence rate of 1.86 per 1,000 hours. Of these, 66.7% (18 cases) occurred during training, and 33.3% (9 cases) during competitions.

The most common injury mechanism was collisions with the opponent's wheelchair or player. The majority of injuries caused 4–7 days of absence (mild), with the shoulder and clavicle being the most affected anatomical regions. Muscle cramps and spasms were the most frequent injury type, with 33.3% acute and 66.7% chronic injuries. Additionally, 63% of injuries were recurrent, and 37% were new.

Wheelchair basketball is one of the most popular adaptive sports, with dedicated leagues for youth, intercollegiate, and adults across various divisions in the United States (Sá et al., 2022). However, a review found limited studies focused on wheelchair basketball, all of which were cross-sectional (Sá et al., 2022). Literature review revealed no studies specifically examining sports injuries in elite female wheelchair basketball players in Iran. However, several international studies have explored injury prevalence, including those by Kasitinon et al. (2021a), Hollander et al. (2020), and Weith et al. (2023c). Kasitinon et al. (2021a) reported 62 health-related incidents, including 48 injuries and 14 illnesses, with injury incidence rates of 12.2 and 13.1 per 1,000 athlete-exposures for men and women, respectively. Hollander et al. (2020) monitored injuries during the 2018 Wheelchair Basketball World Championships, reporting 100 injuries among 132 players, equivalent to 75.8 injuries per 100 players. Weith et al. (2023c) reported injuries and illnesses in elite players over a full season, with patterns similar to championship events.

This study found that nearly half (42.9%) of elite national female athletes reported injuries in the past year. Given the contact nature of the sport and its mechanics, involving high-speed wheelchair movements, significant collision-related injuries are expected. The injury incidence rate of 1.86 per 1,000 hours was lower than in previous studies, likely due to differences in exposure measurement units and competition levels, as prior studies focused on high-intensity events like the 2012 London and 2016 Rio Paralympics (Brombacher et al., 2025). A study from the 2012 London Paralympics observed varied injury epidemiology across sports, highlighting the need for sport-specific longitudinal studies (Brombacher et al., 2025; Engebretsen et al., 2013). Reported injury incidence rates were 12 per 1,000 athlete-days in 2012 (Brombacher et al., 2025) and 12.8 in 2016 (Derman et al., 2018). Differences in injury prevalence and incidence may stem from variations in training intensity, competition level, match duration, tournament type, and participant numbers. The highly competitive nature of international events like the Paralympics likely accounts for these discrepancies. It should be noted that direct comparison of injury incidence rates across studies should be made with caution. The current study calculated injury incidence based on hours of exposure, whereas some previous studies, such as Kasitinon et al. (2021a), reported rates per 1,000 athlete-exposures. This methodological difference in the denominator limits direct equivalence of incidence rates. Nevertheless, the present findings are more comparable to studies that also utilized exposure hours, such as Hollander et al. (2020).

Training injuries (66.7%) were more frequent than competition injuries (33.3%). This aligns with Kasitinon et al. (2021a), who reported higher injury rates during training (76% in men, 91.3% in women) compared to competitions (24% in men, 8.7% in women). However, Hollander et al. (2020) reported 68 injuries during competitions and 32 during training, contrasting with this study. The higher training injury rate in this study may be attributed to the sample's gender and fewer competition opportunities for women in Iran, reducing competition-related exposure. Additionally, training duration (minimum three sessions per week, 1–2 hours each) and inadequate warm-up times (55.6% <15 minutes, 31.7% 15–30 minutes, 12.7% 31–45 minutes) likely contributed to higher training injuries, potentially exacerbated by the physical activity paradox where intensive occupational-like training increases health risks unlike leisure activity (Holtermann et al., 2018). The majority of injuries were mild (4–7 days absence). Limited studies have examined injury severity, but Hollander et al. (2020) reported a median absence duration of 8 days.

Injury epidemiology studies emphasize the importance of identifying affected anatomical regions to enhance prevention and control strategies. The shoulder and clavicle were the most affected regions, consistent with prior studies showing upper limb injuries, particularly in the shoulder, elbow, wrist, and fingers, as dominant in wheelchair basketball (Hollander et al., 2020; Kasitinon et al., 2021a; Sá et al., 2022). Kasitinon et al. (2021a) reported 56.3% of injuries in the upper limbs, while Hollander et al. (2020) noted shoulder (14%), elbow (11%), and hand/finger (10%) injuries, alongside cervical (16%) and thoracic (15%) spine injuries. Sá et al. (2022) found the shoulder to be the most affected body region overall (22.1%). Upper limb injuries, particularly in the shoulder, are linked to repetitive movements, limb usage, and techniques required by the sport, such as wheelchair propulsion, shooting, and defense (Karasuyama et al., 2023). The shoulder's anatomical instability increases its injury risk (Cuéllar et al., 2017), and interventions like kinesiology taping may improve scapular control and reduce impingement symptoms (Shih et al., 2018a). Unlike traditional basketball, where force originates from the lower limbs, wheelchair basketball relies on the trunk and upper limbs, contributing to lumbar and upper limb injuries (Sá et al., 2022).

Conclusions

This study found a low sports injury incidence rate (1.86 per 1,000 hours) among elite female wheelchair basketball players. The most common injury mechanism was collisions with opponents or their wheelchairs (33.3%), with muscle cramps/spasms (37%) being the most frequent injury type and mild injuries (37%) predominant. Most injuries occurred in the upper limbs, particularly the shoulder and clavicle (51.9%), with higher injury rates during training than competitions. Additionally, 63% of injuries were recurrent, and 66.7% were chronic. No prior studies on wheelchair basketball injury epidemiology exist in Iran, and international studies show inconsistent findings (Sá et al., 2022). Given the importance of these results, injury prevention may be helpful to minimize injuries. Coaches, athletes, and stakeholders may help reducing injury rates through targeted prevention programs.

Study Limitations. This study has limitations, including its retrospective design and reliance on online questionnaires with a limited sample size. Retrospective studies may be subject to recall bias which may affect injury reporting and incidence estimates, as participants may not fully or accurately recall past injuries. The study was single-gender, focusing only on female athletes, and did not account for disability classification in the epidemiology analysis.

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Original article

Contextual Governance: Determinants of the International Success of Iranian Paralympians

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Abstract. Iran's success in international Paralympic arenas is the result of a complex and coordinated interaction among structural, institutional, cultural, and social factors. Accordingly, the present study aimed to examine the contextual governance factors influencing the success of Iranian Paralympians in international events, employing a qualitative approach and thematic analysis method. Data were collected through semi-structured interviews with 13 managers, coaches, and experts in the field of the Paralympic movement using purposive sampling and were analyzed inductively. The findings indicated that components such as sport policy-making and governance, standard resources and infrastructure, the education system, talent development and athlete progression pathways, sport communication and diplomacy, support mechanisms, media awareness and representation, and cultural and social frameworks play a fundamental role in Iran's Paralympic success on the global stage. The final analysis suggests that this success extends beyond mere athletic achievements and is the outcome of a structured and systematic process grounded in strategic policy-making, macro-level planning, and synergy among various levels of governance, institution-building, resource allocation, and human and cultural capacity building. Therefore, sustaining this trajectory requires redefining managerial structures, strengthening talent identification systems, developing coach education, designing athlete-centered training environments, paying attention to cultural and social dimensions—including positive media representation and institutionalizing the "citizen–athlete" perspective—and adopting a holistic, system-oriented approach committed to social justice, alongside continued strategic investment and the strengthening of supportive infrastructure.

Keywords. Sport governance, policy-making, classification, parasport, media representation

Introduction

In recent decades, the evolution of the Paralympic Movement has been less a matter of merely expanding sporting competitions and more a reflection of transformations in sport governance models at the global level (Reis et al., 2017). The vision of the International Paralympic Committee (IPC), namely “to enable Para athletes to achieve sporting excellence and inspire and excite the world” (IPC, 2015), can only be realized within efficient, accountable, and inclusive governance systems. From this perspective, Paralympic success is the outcome of institutional, policy, and structural interactions at both national and international levels (De Bosscher et al., 2015).

In this study, governance is defined as “*formalized systems of meaning that embody moral order and operate through explaining and justifying the proper allocation of power and resources*” (Fiss, 2008, p. 391). Accordingly, governance constitutes an institutional framework within which the distribution of resources, access to opportunities, the definition of strategic priorities, and the legitimation of sport actors are determined (Pankowiak et al., 2023). Therefore, countries’ positions in the Paralympic Games may be considered an indicator of the quality of their elite sport governance (Sotiriadou et al., 2017).

The remarkable growth in the number of participating countries, the increase in athletes, and the expansion of the commercial and media dimensions of the Paralympic Games have transformed this event into a competitive arena at the level of national policymaking (Pourkiani et al., 2023). From the first edition of the Games with approximately 20 participating countries to the Paris 2024 Games with 184 countries, the Paralympics have become a global field for assessing countries’ institutional and managerial capacities (Afrouzeh, 2021; Statista, 2024). The signing of the cooperation agreement between the International Olympic Committee and the International Paralympic Committee in 2001, through managerial, financial, and hosting synergies, further elevated the governance status of the Paralympic Games within global sport policy (Legg & Steadward, 2013).

Simultaneously, the expansion of disability rights discourse and the emphasis on the equal right of persons with disabilities to participate in professional sport have prompted national policies to reconsider governance structures in disability sport (Dowling et al., 2018). In this context, Paralympic success is perceived as an instrument for achieving diplomatic, ideological, and social objectives, as well as demonstrating a country’s commitment to equality and social inclusion (Beacom & Brittain, 2016). Consequently, many countries, by strengthening elite sport policies and reforming governance mechanisms, seek to consolidate their position within the competitive Paralympic system (Pourkiani et al., 2023).

Within this landscape, Iran, as one of the active countries in the Paralympic Movement, has in recent years pursued strategic planning and targeted policymaking to enhance its position in the medal table. The trajectory of Iran’s results across different editions of the Paralympic Games indicates that the governance of Paralympic sport in the country, with a focus on resource allocation, infrastructure development, and support for elite athletes, seeks to gain credibility and legitimacy at the international level. Nevertheless, a comprehensive understanding of these achievements requires an in-depth examination of the contextual dimensions of governance.

The Paralympic Movement differs structurally and organizationally from the Olympic Movement, affecting governance and policy influence (Reis et al., 2017). Disability sport federations are generally smaller and less influential than Olympic federations, limiting their ability to shape national sport policies and engage governments effectively (Thomas, 2004; Sotiriadou et al., 2017). Consequently, governments often remain distant from Paralympic sports, and policymaking for athlete development and success faces significant challenges.

Internationally, Paralympic sports are governed through three models: independent federations (e.g., World Para Volley), branches of Olympic federations (e.g., Para taekwondo), or directly by the International Paralympic Committee (e.g., Para powerlifting) (Afrouzeh, 2021). At the national level, governance varies by country. In Iran, Para athletics, Para powerlifting, and Para swimming are under the Sports Federation for Veterans and Persons with Disabilities, while judo and goalball fall under the Sports Federation for the Blind and Visually Impaired; some sports, like Para canoe, are administered by Olympic federations (Pourkiani et al., 2023). In Brazil, many disability sports are managed directly by the Brazilian National Paralympic Committee (Filho, 2024), whereas in Norway, Paralympic sports are organized under Olympic federations and financially supported by the national sport confederation. These structural differences highlight the complexity of Paralympic governance, the variability of institutional arrangements across countries, and the implications for athlete support, policy development, and international competitiveness.

In addition to these structural and governance differences, Paralympic athletes worldwide often face limited access to advanced technology, appropriate equipment, and sponsorship opportunities. Moreover, their voices are frequently underrepresented in sport decision-making processes (deCastro et al., 2016). These factors render policymaking and planning for Paralympic athlete success considerably more challenging and complex than for Olympic athletes (Filho, 2024).

In this context, De Bosscher et al. (2006) identified nine fundamental pillars for athlete success: financial support, an integrated system of development policies, sport participation, talent identification and development, athlete career and post-retirement support, training facilities, coach development, national and international competitions, and finally, scientific research. The amount of budget allocated to the sports system is considered the best predictor of sporting success. However, it should be noted that this does not imply that more money automatically results in more medals. Nevertheless, countries aiming for success in international competitions and to maintain competitiveness must sustain or increase their sports funding. They also stated that the most efficient countries are those that can win the highest number of medals with the least budget. Policies on sport participation and talent identification may not be prioritized for short-term success, but they are crucial factors for long-term achievement. Facilities, coaches and technical staff, and opportunities for national and international competitions also have a direct impact on the sports system, ultimately leading to improved athlete performance (De Bosscher et al., 2015).

Another framework applied in this area is the Success Resources Framework (Digel et al., 2006). They argued that an effective system and structure for sporting success increasingly depend on the surrounding environment and therefore proposed a three-layer model. The first level is the societal level, which includes education and research, economic and political conditions, social structures, and media. The second level is the organizational and sport structures, encompassing management, human resources, athletes, coaches, referees, reward systems, anti-doping, talent identification and development, and training. The third and final level is professional sport and its immediate environment, referring to factors that directly influence professional athletic performance. Wicker and Breuer (2011), applying this same model, examined German non-profit sport organizations and introduced four key factors of sporting success: human resource capacity, financial capacity, communication and networking capacity, and infrastructure and process capacity.

However, studies and models on the governance of success factors in disability sport are limited, which are discussed below. Patatas et al. (2022) compared elite sport policies in the Olympic and Paralympic contexts. They showed that Paralympic sports require higher costs and budgets, involve more stakeholders, and lack a structured talent identification system. Furthermore, the migration of coaches from Olympic to Paralympic sports, the absence of scientific research, and insufficient competitive opportunities are other key differences between the development and success structures of Olympic and Paralympic sports.

Pankowiak et al. (2023), in a qualitative study based on interviews with disability sport experts from Australia, England, Canada, and France, examined the policies of national Paralympic committees and their role in national and international success. Their findings indicated that the development and success policies of Olympic sports should also be applied within the Paralympic structure, emphasizing the implementation of inclusion and integration policies, the incorporation of disability expertise into Olympic sport, and the development of a systematic framework for classifying athletes with disabilities.

Similarly, Peake and Davies (2024) identified success factors for para-athletes in track and field in England, highlighting three specific factors for these athletes: attention to the type and nature of disability, the need for specialized equipment, and individualized athlete care as the most important and distinctive success factors.

Most domestic research in the field of disability sport has focused on sport participation, emphasizing barriers, facilitating factors, and legal dimensions (Limoochi et al., 2020; Vakili Tanha et al., 2020; Zeytoonli, 2018). However, few studies have addressed policy-making and Paralympic athlete success. For example, Shabani and Mostafavi (2022) identified factors affecting the success of Iran’s national sitting volleyball team. They highlighted several key factors, including a large sitting volleyball community and national team support, preparatory and official competitions, appropriate facilities and equipment, professional coaching staff, and a suitable talent identification process. They also identified management, proper planning, and governance support as enabling conditions.

Naderian et al. (2023) analyzed legal policy-making in championship sports for persons with disabilities, showing that financial and media policies contain negative aspects requiring review. Additionally, Pourkiani et al. (2023) examined changes in the governance of Paralympic sports in Iran, showing that governance changes in some cases (e.g., para-canoeing) led to improved athlete performance and success, whereas in other cases (e.g., para-archery) they caused challenges and technical decline among athletes.

In recent decades, the Paralympic Games have become a strategic platform for demonstrating national capabilities, social progress, and commitment to disability rights. Iran has pursued long-term investments and policies to improve medal rankings and project a positive international image. Success depends on complex, multi-level factors: macro-level governance, legal and economic structures; meso-level organizational support; and micro-level influences such as clubs, coaches, families, and athletes. Key determinants include governance, sustainable resources, access to facilities and equipment, talent identification, policy coherence, international connections, and societal and media perceptions of athletes with disabilities.

In Iran, despite some notable achievements in winning Paralympic medals, evidence indicates that multiple challenges persist in the path toward sustainable development and long-term success in this field. Weak structural integration among related federations, fragmentation and misalignment of responsibilities, inadequate training infrastructure, instability of financial resources, deficiencies in comprehensive talent identification systems, and limited involvement of non-governmental organizations and the private sector in the development of disability sport are among the key obstacles that policymakers and planners must address.

Moreover, structural and institutional differences between Olympic and Paralympic systems mean that success models in these two domains cannot be fully generalized from one to the other. The unique characteristics of Paralympic athletes, technical requirements and specialized equipment, the complexities of disability classification, and the need for comprehensive and inclusive policies all necessitate that any analysis of Iran's success in the Paralympics be conducted with careful consideration of the country's specific social, institutional, and economic contexts.

Methods

Given the limited empirical resources on governance factors affecting Iranian Paralympians' international success, this study is a qualitative exploratory inquiry. It is applied in nature, aiming to identify and analyze contextual dimensions to inform effective national policy-making in elite disability sports. The research follows an interpretive paradigm, emphasizing participants' social experiences and meaning-making.

An inductive approach guided data analysis, allowing concepts and patterns to emerge directly from the data without prior theoretical assumptions. Thematic analysis, based on Braun and Clarke's six-step method (2006), was employed. Data sources included semi-structured interviews with 13 purposefully selected experts, managers, coaches, and key actors within Iran's Paralympic system, as well as theoretical texts and policy documents. Thematic coding was used to extract key themes and motifs.

Participants were selected through the authors' professional network, ensuring diversity in administrative, academic, and practical experiences. Semi-structured interviews were chosen as the primary data collection tool due to their suitability in contexts with limited prior knowledge (Richards & Morse, 2012). This approach enabled in-depth exploration of participants' perspectives, capturing nuanced insights into governance structures, resource allocation, institutional practices, and contextual factors influencing athlete development and performance at national and international levels.

Table 1. Demographic Characteristics of Research Participants

No.	Education	Experience (with ethical identity considerations)
1	PhD	PhD in Management, researcher in Paralympic field
2	PhD	PhD in Management, researcher in the Paralympic field
3	PhD	University professor and researcher in Paralympic field
4	PhD	Technical Deputy, Iran Paralympic Committee
5	Master’s	Former Technical Deputy, Irn Sport Disable Federation
6	Master’s	Former Technical Deputy, Iran Paralympic Committee
7	PhD student	Athlete
8	PhD student	Athlete and member of the Iran Paralympic Athletes’ Commission
9	PhD	Former Technical Expert, Iran Paralympic Committee
10	PhD student	PhD student in Sport Management and Track & Field athlete
11	PhD	University professor and researcher in Paralympic field
12	PhD	PhD in Management, researcher in Paralympic field
13	PhD	Manager in Iran Paralympic Committee

The data collection in this study was conducted systematically to obtain rich insights into the contextual governance factors influencing the success of Iranian Paralympians in international competitions. A semi-structured interview guide was developed based on theoretical literature and study objectives, including key themes while remaining flexible to allow in-depth exploration. Two pilot interviews tested the guide’s content and operational validity, leading to question revisions for clarity and the addition of new items to cover overlooked dimensions, enhancing internal consistency and data depth.

Thirteen participants—managers, coaches, experts, and national athletes—were purposefully selected based on theoretical criteria. Sample questions addressed governance structures, financial and logistical support, specialized knowledge in rehabilitation and disability sports, and initiatives in cultural promotion and media representation. Participants received the guide prior to interviews, and informed consent, confidentiality, and withdrawal rights were ensured. Interviews were conducted between February and May 2025, either in person or by phone, each lasting 30–45 minutes and audio-recorded with permission. The researcher maintained an open, non-directive dialogue, intervening only for clarification (Høffding & Martiny, 2016; Rahman, 2023).

All interviews were transcribed verbatim and analyzed using Braun and Clarke’s (2006) six-phase thematic analysis: familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and reporting. Semantic and latent coding were applied, with constant comparison across interviews. Themes were reviewed for coherence, distinctiveness, and interpretive depth, ensuring they reflected participants' experiences (Braun & Clarke, 2013; Clarke & Braun, 2016). The final report presents a concise, logical narrative structured around the identified themes.

Trustworthiness was established through credibility, transferability, confirmability, and dependability (Guba & Lincoln, 1994). Presenting themes as primary analytical units, contextualized with prior studies, provided a nuanced understanding of participants' perspectives. This systematic and rigorous approach ensured that findings accurately reflect the governance, structural, and socio-cultural factors shaping the success of Iranian Paralympians, supporting both theoretical and practical insights.

Findings

After analyzing the research data, the initial codes, concepts, and themes were presented in Table 2.

Table 2. Coding of Research Data

Themes	Concepts	Initial Codes
Policy-making	Strategic Policy-making	Agency coordination, long-term goals, alignment with higher-level policies, flexible transparent policymaking, stakeholder participation, international trend consideration, national–provincial coherence, forward-looking policies, global experience use, Paralympic focus, continuous evaluation, coherent discourse, advisory body strengthening.
	Institutional Structure	Strengthening specialized institutions, clear executive responsibilities, agile decision-making, structural support for Paralympic athletes, effective communication channels, systematic accountability, government–NGO interaction, empowered civil society, internal advisory and oversight structures, vertical–horizontal connectivity, coordination of research, education, and implementation, expertise diversity, and institutionalized knowledge management.
	Competitive Planning	Designing athlete development pathways, setting realistic international goals, regular competitions, analyzing global competitors, localizing readiness models, diversifying preparatory events, performance evaluation via competitive indicators, long-term cyclical planning, targeted pre-competition camps, talent-to-champion development, aligning training with global calendars, involving international experts, and providing psychological, medical, and nutritional support.
	Inter-Organizational Coordination	Clarifying organizational roles, signing inter-institutional agreements, forming committees, using horizontal coordination, enhancing interactions via shared interests, establishing task referral systems, integrated communication networks, facilitating

		information flow, leveraging complementary capacities, reducing overlaps, developing sustainable cooperation, standardizing interactions, mutual support in events, and exchanging knowledge and experience.
	Resource Management	Optimal financial allocation, diversified funding, specialized human resources, transparent spending, private sector support, resource effectiveness evaluation, engagement of philanthropists, efficient infrastructure use, managerial capacity building, transparent supervision, sustainable logistics, leveraging sponsorship, balanced distribution, and targeted reward systems.
Resources and Infrastructure	Allocatable Financial Resources	Available Budget, Continuous Funding, Resource Investment, Effective Financial Management, Appropriate Budget Allocation, Sustainable Financial Support, Sufficient Economic Resources
	Adequate Training Facilities	Standard Training Facilities, Equipped Training Halls, Training Schedule Planning, Favorable Environmental Conditions, Access to Sports Venues, Improvement of Training Infrastructure, Sports Technical Facilities
	Standardized Equipment	Up-to-date Sports Equipment, High-quality Gear, Specialized Equipment, Technical Standards of Equipment, Equipment Updates, Equipment Suited to Sporting Needs
	Sports Venue Capacity	Inclusivity of Sports Venues, Capacity to Accommodate Para Athletes, Optimal Use of Space, Number of Sports Facilities, Geographic Distribution of Venues, Ancillary Amenities of Facilities
	Access to Specialized Resources	Access to Experienced Coaches, Utilization of Expert Specialists, Scientific and Research Resources, Professional Networks, Specialized Training, Technical Consultation, Knowledge-Based Resources
Education System	Athlete-Centered Training	Enhancing personal capabilities, active athlete learning, attention to individual differences, athlete participation in the learning process, development of mental and physical skills, continuous feedback, improvement of motivation and commitment, creating a supportive environment, personalized approach in training
	Coach Knowledge Development	Updating specialized knowledge, training in new coaching skills, enhancing scientific understanding of coaches, utilizing recent research, strengthening performance analysis skills, training in communication skills, team management training, expanding

		knowledge of sports psychology, empowerment in decision-making, using educational technologies
	Educational Content Design	Developing targeted educational programs, structuring educational content, using modern teaching methods, utilizing multimedia resources, focusing on learning objectives, content flexibility, addressing learner needs, creating engaging and interactive content, logical organization of materials, continuous content updates
	Technical Advancement System	Performance assessment criteria, technical progress planning, continuous skills evaluation, encouragement of lifelong learning, defining promotion levels, feedback mechanisms, use of qualitative indicators, focus on improving specialized skills, transparency in promotion processes, organizational support for technical development
Talent Identification and Athlete Development	Talent pathway	Identifying movement capacities, discovering potential abilities, monitoring interests and motivations, initial performance assessment, mapping capabilities, recruiting young athletes, matching abilities with suitable sports, creating a talent database, measuring physical potential, psycho-cognitive assessment, tracking early progress, identifying strengths, setting entry criteria for professional pathways, considering diversity of disabilities, expanding identification networks, documenting talents
	Functional classification	Assessing and classifying disability, measuring physical fitness, motor independence, technique, adaptability, and technical skills, standardizing evaluations per global and Paralympic standards.
	Individual development process	Personalized training, technical and mental skill development, performance monitoring, nutrition, motivation, team coordination, rehabilitation, assistive technology, feedback, stress management, and self-confidence enhancement.
	Elite progression pathways	Goal setting, physical readiness, competition experience, strategic and tactical skills, specialized camps, performance evaluation, social and technical support, psychological preparation, recovery management, competitor analysis, international participation, playing style consolidation, alignment with Paralympic standards.
	Individual development design	Assessing athlete needs, identifying strengths, designing personalized training, scheduling progression, coordinating with medical/technical teams, setting objectives, providing resources, continuous feedback, monitoring health, adapting to environment, sustaining motivation, documenting progress, enhancing

		management, considering social/family factors, promoting self-reliance.
Sports Communication and Diplomacy	International interaction	Transnational communication, global collaboration, cultural exchange, participation in international events, coordination with global organizations, enhancing international standing, interaction with other Paralympic committees, building communication bridges, exchange of knowledge and information
	Participation in associations	Active membership, participation in professional assemblies, attending specialized meetings, exchanging perspectives, forming professional networks, increasing social interactions, developing professional relationships, presence in working groups, involvement in decision-making, fostering a sense of collective belonging
	Sports networking	Establishing professional connections, developing professional relationships, strengthening team cohesion, creating support networks, connecting to sports resources, liaising with sponsors, increasing collaboration opportunities, sharing information, mutual support in competitions, enhancing status within the sports community
Supporting System	Educational Support	Specialized coach training, enhancing athletes' technical skills, access to educational resources, conducting skill workshops, training on Paralympic rules and regulations, improving sports literacy, training in planning exercises, developing specialized knowledge, transferring experience from former champions, using modern educational technologies, empowerment in self-management
	Psychological Support	Sports psychology counseling, stress and anxiety management, sustaining motivation, enhancing resilience, team emotional support, training coping skills, boosting self-confidence, facilitating supportive connections, creating a positive psychological environment, mindfulness practice, improving competition focus
	Sustainable Financial Support	Regular budget allocation, financial support through sponsors, covering equipment costs, granting sports scholarships, covering travel and accommodation expenses, regular salary payments, establishing financial support funds, attracting long-term investments, supporting development projects, providing emergency financial aid
	Social Support	Creating support networks, family and community participation, enhancing social interactions, promoting a culture of respect for Paralympic athletes, appropriate media presence, organizing social

		events, support from NGOs, developing volunteer groups, increasing public awareness, enhancing social cohesion
	Rehabilitation Services	Access to rehabilitation equipment, specialized physiotherapy services, movement rehabilitation programs, training in using assistive devices, health counseling services, monitoring physical condition, improving overall health, supporting post-injury rehabilitation, access to specialized centers, periodic competency evaluations
	Sports Logistics	Providing appropriate sports equipment, managing transportation, scheduling training and competition, coordinating athlete accommodation, ensuring proper nutrition, technical support at competition venues, managing sports resources, providing safety equipment, access to training facilities, facilitating administrative procedures
	Technological Support	Using machine learning algorithms to predict injury probability, recording and analyzing training data via wearable sensors, collaborating with tech companies to enhance adaptive equipment, processing big data for individualized training planning, developing digital rehabilitation software for mobile and tablet, utilizing digital platforms for real-time feedback and progress monitoring
Public Awareness and Social Representation	Storytelling	Shaping sports stories, narrating successes, constructing sports identity, highlighting Paralympic champions, sharing athletes' experiences, positive storytelling, creating narratives of solidarity, representing achievements, motivational narratives, social participation stories, revisiting history, inspirational narratives, building cultural narratives, media storytelling, sports storytelling
	News Coverage	Event reporting, publishing competition news, live coverage, media analysis, news topic selection, visual reporting, reflecting activities, event media coverage, public information dissemination, analytical coverage, focus on athletes, team representation, multimedia coverage, news planning, media feedback
	Cultural Promotion	Promoting Paralympic values, public education, developing sports culture, enhancing social acceptance, awareness programs, promotional activities, encouraging participation, fostering a culture of support for disability, increasing public knowledge, social culture-building, promoting mutual respect, creating positive environments, enhancing empathy, informational programs, changing attitudes

	Public Dialogues	Social debates, public discussions, conversations about sports, citizen participation, intergroup interaction, cultural dialogue, exchanging viewpoints, social dialogues, creating spaces for conversation, listening to community voices, discussing disability, media debates, stakeholder interaction, interactive conversations, specialized discussions
Cultural and Social Frameworks	Public Attitude toward Participation	Public support and acceptance, valuing abilities, community interest, recognition of achievements, respect for commitment and choices, promoting participation and fairness, fostering belonging, empathy, awareness, justice, equality, and belief in capacities..
	Athletes' Social Status	Symbolic and exemplary roles, social credibility, equal status, positive role models, visibility, ethical commitment, respected position, cultural influence, participation in decisions and social activities, development opportunities, enhanced identity, supportive environment, media engagement.
	Cultural Frameworks for Activity	Cultural infrastructure, diversity acceptance, inclusive spaces, support for Paralympic activities, respect for differences, participation values, cultural education, supportive institutions, mass sport promotion, specialized training, empathy, appropriate facilities, intercultural interaction, rights awareness, empowerment culture.
	Community Interaction with Athletes	Collaboration, support networks, active participation, dialogue, motivation, resource access, group convergence, mutual respect, participation opportunities, experience sharing, attention to special needs, team spirit, growth support, peaceful coexistence, positive media, feedback, empathy, sustainable development..

Discussion

Policy-making. The findings indicate that strategic policymaking in disability sport—particularly within the Iranian Paralympic context—plays a decisive role in achieving international success. While Olympic athletes typically benefit from more extensive infrastructure and coherent talent identification pathways, Paralympic athletes face distinct challenges, including unequal access to facilities, diverse rehabilitation needs, and complex classification requirements. Consequently, they require more precise, specialized, and functionally tailored policy frameworks. Although the Paralympic movement is formally positioned alongside the Olympic movement in national upstream policy documents, the shifting of certain sport disciplines between specialized federations and the Veterans and Disabled Sports Federation reflects a lack of a holistic and strategic perspective, leading to fragmented actions and inefficient resource allocation. As prior studies emphasize (Pourkiani, Afrouzeh, & Boroumand, 2023), effective policymaking must move beyond short-term and reactive approaches and instead be grounded in robust evidence and systematic needs assessment (Brittain, 2010). Moreover, Paralympic success is strongly contingent upon a transparent and coordinated institutional structure (Papatheodorou et al., 2020). Overlapping mandates among entities such as the National Paralympic Committee, the Ministry of Sport and Youth, the Welfare Organization, and other governmental bodies further underscore the need for clearly defined organizational boundaries and accountability mechanisms.

At the operational level, systematic elite sport planning constitutes a cornerstone of international preparedness (Pankowiak et al., 2023). However, in the Paralympic domain, the diversity of functional groups and medical classifications necessitates more individualized and specialized program design (Peake & Davis, 2024). These distinctions extend beyond technical preparation to psychological and logistical dimensions, requiring careful management of training loads, fatigue, and sustained support systems. Accordingly, transitioning from fragmented, event-driven approaches to a stable and system-oriented planning model is particularly critical for athletes with disabilities.

In this regard, shifting from a "project-based" approach toward "evidence-based governance" requires reconstructing Iran's Paralympic policy ecosystem through a polycentric model. Such a model should emphasize vertical alignment with national strategic documents and long-term development visions, strengthened horizontal engagement with key stakeholders—particularly disability-focused NGOs—and the establishment of a monitoring and evaluation system based on updated key performance indicators aligned with contemporary Paralympic frameworks. This multi-level governance approach can foster adaptive, transparent, and accountable policymaking and contribute to the sustainable development of the Iranian Paralympic movement.

Resources and Infrastructure. In the development of Paralympic sport in Iran, resources and infrastructure constitute one of the most fundamental yet challenging domains, significantly influencing participation quality, training continuity, and international success. This domain extends beyond financial allocations and physical facilities to encompass specialized equipment, skilled human resources, spatial capacity-building, and knowledge support. Although the growing recognition of the Paralympic Games has led governments to increase public investment in Paralympic sport policies (Pourkiani et al., 2023), analysis of the 1404 (2025–2026) national budget reveals a persistent gap between actual needs and existing capacities. The National Paralympic Committee has been allocated 356 billion tomans, of which 350 billion are devoted to current expenditures and only 6 billion (less than 2%) to capital development. Additionally, 300 billion tomans have been jointly allocated to the National Olympic and Paralympic Committees for the Asian Games, with a further 30 billion provided through miscellaneous budget lines (Iranian Parliament Research Center, 2025). Despite seemingly substantial figures, the minimal share of capital funding indicates limited commitment to long-term infrastructure, facilities, and specialized training environments. A uniform approach to resource allocation fails to capture the specific needs of different disciplines (Papatheodorou et al., 2022). Para-athletics, particularly track and field for athletes with visual impairments, has delivered a significant proportion of Iran's Paralympic medals but represents one of the most complex and resource-intensive disciplines (Peake et al., 2025). The wide range of classifications (T/F11–57) requires individualized programming and highly specialized equipment, including racing and throwing wheelchairs, customized prostheses, and stabilization devices. Yet many Iranian sport facilities were not originally designed for para-athletes, resulting in shared or unsafe environments that compromise training quality and increase injury risk (Pourkiani et al., 2023). Moreover, international sanctions, currency constraints, and the absence of official suppliers hinder equipment importation, while domestic production remains below international standards. The lack of technical specialists for maintenance and calibration of sophisticated equipment further weakens the supply chain. Given that Paralympic equipment is costly, personalized, and non-transferable, financial disparities directly translate into performance inequalities (Peake et al., 2025).

Therefore, financial management must move beyond covering operational costs toward a long-term investment strategy focused on specialized equipment, rehabilitation technologies, and infrastructure development. Transparent, data-driven performance-based reward systems and digital financial monitoring mechanisms can enhance efficiency and accountability. Addressing current financial short-termism requires innovative solutions, such as establishing a joint public–private investment fund to secure sustainable resources for technological advancement and infrastructural growth in Iranian Paralympic sport.

Education System. One of the primary determinants of Paralympic success is coaches' knowledge of disability. Evidence suggests that such knowledge is rarely delivered through formal or systematic education; rather, it is developed experientially through direct interaction with athletes and families and through trial-and-error processes. Given that classification systems in Paralympic sport are continuously evolving, disability cannot be treated as a static medical category but must be understood as functionally dynamic and context-dependent. Coaches with deeper understanding of classification and functional profiles are better positioned to guide athletes along elite pathways; without such knowledge, disability risks becoming a structural barrier rather than a manageable performance variable.

Due to the wide variation in type and severity of impairments, standardized approaches are ineffective. Effective coaching requires individualized understanding of athletes' physical characteristics, prior psychological experiences (e.g., trauma or anxiety), and cognitive, emotional, and motivational differences. Accordingly, training environments must be tailored to athletes' capacities within an athlete-centered support ecosystem, where performance outcomes depend not only on physical preparation but also on coordinated collaboration among coaches, psychologists, families, and institutional actors.

Paralympic athletes are exposed to multidimensional stressors, particularly during international travel, high-stakes competition, and social expectation pressures. Coaches therefore need awareness of athletes' psychological backgrounds, contingency planning skills, and competencies in stress management, emotional regulation, and psychological support, alongside the ability to balance decisive leadership with empathy.

Empirical studies (Pankowiak et al., 2023; Patatas et al., 2018, 2022; Peake & Davis, 2024; Pourkiani et al., 2023; Rahman, 2023; Rees et al., 2017; Richards & Morse, 2012; Seifpanahi Shabani & Mostafavi, 2022; Sotiriadou et al., 2017; Thomas, 2004) consistently identify psychological preparedness and resilience as key predictors of elite Paralympic performance. Coates and Howe (2023) further highlight rehabilitation centers as critical entry points into sport, where informed personnel can facilitate early engagement and talent identification. Without adequate informational, motivational, and structural support at this stage, potential talent may remain unrealized. Strengthening collaboration between mainstream sport institutions and the Paralympic system—particularly through training teachers and rehabilitation staff—can enhance the talent identification pathway and long-term success.

Talent and Athlete Development. Primary support structures must be strengthened as bridges between everyday life and elite sport. A schoolteacher or physiotherapist with sport-specific knowledge can represent the first link in an athlete's success pathway (Coates & Howe, 2023). During talent identification processes, the presence of coaches alone is insufficient; deep understanding of classification systems and disability characteristics is essential. Decisions regarding sport selection or competitive potential made without such expertise risk unrealistic expectations, disappointment, and early dropout. Since classification in Paralympic sport functions as a mechanism for leveling competitive readiness, inadequate knowledge can lead to misallocation of human resources and disrupted development pathways. Thus, training talent identification specialists in classification represents a critical structural success factor.

Recruitment often occurs through self-referral to local clubs; therefore, these clubs must possess basic knowledge, appropriate equipment, and an inclusive mindset. Well-prepared clubs can significantly contribute to athletes' psychological, physical, and technical development, whereas inadequate awareness may result in early discouragement or isolation.

Gender norms and adolescence further complicate participation, particularly in the context of disability. Parents often exert strong influence and may adopt overprotective behaviors. However, evidence suggests that early sport participation for girls reduces negative self-perceptions during adolescence. Accordingly, family education and supportive environments are essential (Baker et al., 2020; Mann, Dehghansai & Baker, 2017; Dehghansai et al., 2017, 2020).

Sports Communication and Diplomacy. International engagement in the Paralympic arena extends beyond competition, functioning as a critical platform for exchanging specialized knowledge, rehabilitation technologies, and governance practices. For athletes competing within complex functional classifications, such interactions enhance technical, psychological, and physical preparation (Pullen, Mora & Silk, 2025).

Nationally, the Paralympic system differs from mainstream and Olympic sport systems due to its strong dependence on inter-organizational collaboration. Athlete identification and development require coordination with entities such as the Welfare Organization, Exceptional Education, healthcare providers, and support services. Participation in international federations and forums enables alignment with global standards and active involvement in policymaking (Brittain, 2016), which is particularly important given the need for precise regulatory and classification adjustments. Exchange initiatives—such as international coaching programs, joint training camps, and technical workshops—further strengthen expertise and skill development (Pullen et al., 2025), while expanding sport networks fosters collaboration and synergy.

Institutionally, agile, transparent, and specialized governance structures are essential for coherent strategic planning across national and local levels. Current fragmentation among the National Paralympic Committee, federations, and ministries generates duplication and inefficiency. Redesigning governance as a multi-layered, collaborative matrix network can improve coordination. Implementing standardized, technology-based data exchange systems—particularly for health, classification, and performance management—would enable real-time information sharing, optimize decision-making, and enhance overall system effectiveness.

Supportive Assistance. Disability sport is intrinsically linked to rehabilitation, serving not only as physical activity but also as a mechanism for social belonging, identity reconstruction, and empowerment (Dantas et al., 2024; Patatas et al., 2018). This dual rehabilitative–competitive nature explains the rapid progression of some athletes to elite national and international levels, despite limited opportunities and a smaller eligible athlete pool, with advancement often occurring within six months to two years (Barzona et al., 2023).

China exemplifies systemic integration of rehabilitation and sport. Since 2014, nationwide programs under the China Disabled Persons' Federation (CDPF)—which also serves as the National Paralympic Committee—have provided long-term, specialized services, including early disability detection, education, employment support, and sport development. In one year, 800 events were held, over 11,000 coaches trained, and 234 provincial centers operated (China Disabled Persons' Federation, 2014). Brazil, in contrast, shows high elite retention but limited renewal, with returning athletes comprising 22–24% in recent

Paralympic Games, while access remains urban-centered (Philo, 2024; Pike et al., 2025).

At the individual level, rehabilitation integrates physiotherapy, adaptive training, and performance assessment to prevent injury and sustain elite performance. Assistive technologies—prosthetics, racing wheelchairs, and mobility aids—must meet international standards to enhance autonomy and confidence. Post-injury care combining medical and psychological support often determines career continuity. Family support is essential but must avoid over-involvement, which can hinder independence (Coates & Howe, 2023). Environmental factors, facilities, clubs, equipment, and qualified coaches—remain critical structural enablers.

Sustainable success requires coordinated institutional support balancing sport, education, and employment, with long-term public–private investment in specialized infrastructure, standardized classification systems, and comprehensive data management. Transitioning from short-term competition-focused strategies to staged developmental pathways enables incremental athlete progression. Advanced analytics, including artificial intelligence and machine learning, optimize training, recovery, injury prevention, and performance efficiency. Finally, success extends beyond medals to sports diplomacy and social capital, with rights-based media narratives and emerging technologies enhancing the global standing of the Paralympic movement.

Awareness and Social Representation. The term “Paralympic” implies parity with the Olympic Games, yet unequal media representation creates a fundamental gap. Paralympic athletes are often depicted either as heroic figures or objects of pity, reducing them from elite athletes to “moral symbols” and potentially undermining material support, official recognition, and intrinsic motivation (Antonovich & Bandon, 2022). Various frameworks—medical, social, relational, and interactional models—explain how society perceives disability and shapes interactions (Patatas et al., 2018). Media narratives predominantly follow the medical model, portraying disability as an individual deficit rather than a product of inaccessible environments. These framing influences coverage, policy, investment, and athletes’ pathways to success.

Adopting a social model perspective, which identifies exclusionary social structures and environmental barriers, can promote inclusion (Barnes, 2020; Brittin et al., 2023). Bodily impairments exist, but oppression arises from societal structures enforcing “normalcy,” e.g., wheelchair users are disabled when environments obstruct mobility. Within Paralympic media coverage, a “disability hierarchy” favors athletes with dramatic, acquired disabilities, creating inequalities in access to resources, coaching, financial support, and psychological motivation. Superficial or stereotypical portrayals diminish athlete status and influence policymaking, budget allocation, and public support. Accurate, balanced, and expertise-driven media representation can thus serve as a strategic tool to empower athletes, raise awareness, and develop supportive infrastructures essential for Paralympic success (Anderson, 2025).

Cultural and Social Frameworks. National and societal cultures profoundly shape Paralympic athletes' attitudes, behaviors, and emotional experiences. In Iran, athletes are often framed within a "charity" discourse, viewed as recipients of benevolence rather than rights-bearing sportspeople, which undermines long-term advocacy for infrastructure and support (Anderson, 2025). High power-distance societies may reinforce helplessness and limit challenge to unequal structures, whereas low power-distance contexts promote egalitarianism, participatory decision-making, and self-esteem. Collectivist cultures link sporting success to national or group pride, strengthening intrinsic motivation but potentially limiting emotional expression. Individualistic cultures, by contrast, encourage personal goal pursuit, self-expression, and motivation. Masculine cultures emphasize competition and victory, increasing stress, while feminine cultures value cooperation, psychological well-being, and team cohesion.

Cultures with high uncertainty avoidance create athletes dependent on structure and sensitive to unexpected changes, increasing stress; low uncertainty avoidance fosters flexibility and adaptability. Long-term oriented societies invest in continuous development, while short-term cultures focus on immediate results, risking sustainable growth. Hedonistic cultures promote joy, confidence, and motivation; restrictive cultures suppress emotional expression and reduce sporting quality. Understanding Paralympic sport ethically requires clarity on ability, disability, and normative standards, forming the basis for policies, support systems, and success evaluation. Developing a coherent "Paralympism philosophy" analogous to Olympism can provide strategic guidance beyond the IPC's declared values of courage, determination, inspiration, and equality (Rajo et al., 2025).

National media, reflecting culture and policy, can facilitate or hinder athlete success. Extensive, expertise-driven coverage attracts sponsors, government attention, and investment in equipment, training, and infrastructure, while neglect limits resources. Positive, multidimensional media narratives can counter stereotypes, promote social recognition, empower athletes, and institutionalize Paralympism's ethics, reinforcing public understanding of ability and strengthening structural and policy support (Wachowski, 2024).

Conclusion

Implementing integration and inclusivity policies in the field of elite sport, particularly at the national level, can be an effective step toward achieving social justice and enabling mutual benefits for both Olympic and Paralympic athletes through shared structural and supportive capacities. Integrating policies in a manner that includes athletes with disabilities within the structures, resources, and strategic planning of Olympic sport not only fosters institutional synergy but also allows for more efficient resource allocation, enhanced training, and increased specialization in the management of athletes with disabilities.

Moreover, incorporating disability-specific expertise into the Olympic sports system and developing a coherent classification framework for Paralympic athletes can standardize procedures and strengthen the legitimacy of Paralympic sport at both national and international levels. This approach, particularly in resource-constrained countries, can provide a foundation for greater integration, efficiency, and coherence in elite sport policymaking.

Iran's success in the Paralympics cannot be analyzed solely in terms of athletic achievements; rather, it reflects a structural and systematic process grounded in strategic policymaking, high-level planning, and continuous interaction among multiple institutions. The findings of this study indicate that Iran's Paralympic success is not only the result of elite athletes' efforts but also the outcome of synergy across various governance levels, institutional development, resource provision, and human and cultural capacity building.

To sustain this trajectory, policymaking institutions must draw inspiration from successful global approaches to redefine management structures, enhance talent identification systems, develop coach education programs, and design individualized, multidimensional training environments. Attention to the cultural and social dimensions of Paralympic sport—including positive media representation, public awareness, and institutionalization of the "citizen-athlete" mindset in society—is also a key pillar of sustaining these achievements.

Within this framework, civil society, non-governmental organizations, and families play an influential role in providing comprehensive support for athletes. Therefore, Iran's future success in the Paralympics requires a holistic, system-oriented, and sustainable approach, in which all components and stakeholders operate in coordination and interaction to achieve the national and human objectives of this arena. Continuous strategic investment, strengthening of technical and supportive infrastructure, and a commitment to social justice will pave the way for Iran to attain its rightful position at the international level.

Research Limitations and Suggestions for Future Research

This study has placed a particular focus on elite athletes and governance structures at the national level, while giving less attention to athletes at the provincial and local levels; consequently, some challenges and opportunities in local environments may not have been fully identified. In addition, access to precise data regarding international interactions and sports diplomacy has been limited. Future research could examine the economic and budgetary aspects of Paralympic sports and quantitatively assess the impact of resource allocation on athlete success, investigate the effects of media, social representation, and local culture on athletes' motivation, performance, and participation using more rigorous empirical and survey methods, and also analyze international interactions, coach exchanges, and experience-sharing programs from the perspective of strategic utilization for the advancement of Paralympic sports in Iran.

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