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Systemic Approach to Injury Phenomenology in Generation Z Padel: Biomechanical Interrelationships and Physical Armor

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Abstract. This work focuses on analyzing how young Generation Z padel players get injured, utilizing a complex systems approach for understanding the process. Our thesis suggests these injuries are not random occurrences; instead, they represent failures in the body's biomechanical balance, primarily triggered by explosive movements and the use of very rigid rackets (such as those made of carbon fiber). To prevent this, we propose the Physical Shielding model, a strategy aimed at restoring bodily tensegrity and making the organism more resilient against mechanical load. A central point is that young athletes often ignore "early warnings" or prodromal states (subtle signs like minor inflammation) because they prioritize immediate performance. Furthermore, we found gender differences in injury patterns: men generally suffer more shoulder issues, while epicondylitis (tennis elbow) is more common in women. Ultimately, the study concludes that we must move beyond traditional training goals to adopt a holistic pre-habilitation strategy that combines ergonomic equipment adjustments, eccentric training, and the player's ability to "listen" to their own body.

Keywords: Padel injuries, injury prevention, biomechanics, Generation Z athletes, Systemic Approach, Physical Shielding

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1. Introduction: The Player as a Complex Biomechanical System

Traditional medicine and sports enthusiasts have historically approached ailments resulting from sports sessions from a reductionist paradigm (Pol, et al., 2024), isolating the body part affected (once injured), from its dynamic context. However, the emergence of Generation Z in padel is characterized by explosive kinematics (regarding the position, speed, and acceleration of players) and a highly rigid technological environment (carbon rackets and concrete floors in some public spaces). This demands the formulation of a new research posture based on the interconnection of all processes (from a systemic point of view).

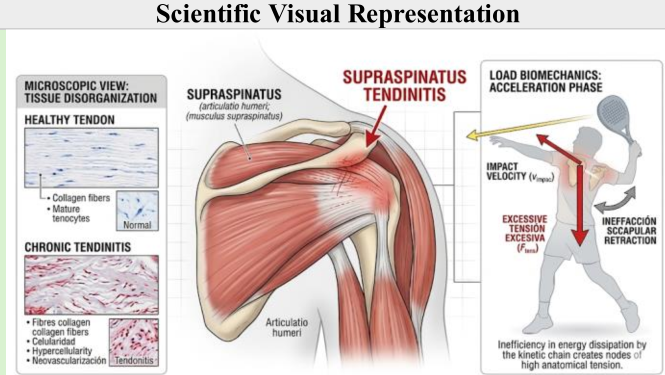
Under this systemic lens, the athlete is not a sum of parts, but a network of interdependent subsystems (network risk profile, Bittencourt et al., 2016). Therefore, an injury is no longer conceived as an isolated accident, is a failure in energy transfer along the kinetic chain that ends up collapsing the weakest link (Hulme et al., 2017). This disruption in biomechanical homeostasis (capacity of living tissues to maintain a stable structural and functional balance against external mechanical loads) indicates a loss in the system's capacity to self-organize in the face of game demands. Recognizing this network physiology (Balagué, et al., 2020), our goal is to decode these systemic interconnections to design a proactive prevention model that we call "Physical Shielding." This model works by restoring the system's balance and ensuring the athlete is fundamentally better prepared, measured by how they perceive injury risk throughout their body, in addition, we show the affected body parts and how they interconnect in the kinetic chain for a better holistic understanding.

2. The Risk Ecosystem and Anatomical Interrelations

To truly understand how the biomechanical system collapses (the loss of the athlete's critical ability to self-organize and maintain balance against outside stress), we must map its dynamic interactions within the immediate environment (Bittencourt et al., 2016). The padel court is an ecosystem where technical equipment acts as a fundamental mediator of force, channeling vibratory and mechanical energy directly into human tissue. This constant interplay demands a coordinated, real-time systemic response from every anatomical node (Balagué et al., 2020). For Generation Z athletes, this is compounded by suboptimal adaptation velocities, a structural mismatch where the speed and power of modern play clash with their age-appropriate growth capacities (Paterno et al., 2013). This mechanical stress, if greater than the body's recovery ability, leads to overuse injuries and the buildup of high anatomical tension. These points of disproportionate load first appear as prodromal states (subtle warnings that, when ignored by the athlete prioritizing immediate performance, inevitably precipitate a definitive structural failure and loss of systemic integrity).

The latest data on amateur players shows that the timing and location of injuries differ significantly based on gender, men tend to have more muscular and ligament problems in the shoulder, alongside tendon issues in the elbow and women, conversely, are more likely to experience muscular injuries in both the shoulder and elbow area, suggesting that biological sex creates specific loading patterns that must be taken into account when developing prevention programs (Muñoz et al., 2022). The resulting tension builds up in joints acting as "compensatory hinges", revealing that stress is distributed inefficiently due to underlying technical faults. To fully grasp the scope of this study, the key terms and their definitions are provided below (see Table 1).

Table 1. Visual Representations and Fundamental Concepts

Systemic Concept and Definition	Scientific Visual Representation
Shoulder Tendinitis: Failure in load management of the glenohumeral subsystem, where inefficient scapular retraction forces the tendinous tissue to absorb the excess energy not dissipated during the acceleration phase.	

<table>
<tr><th>Systemic Concept and Definition</th><th>Scientific Visual Representation</th></tr>
<tr><td>

Epicondylitis (Tennis Elbow): Prodromal manifestation of a collapse in the arm's dissipating terminal, concentrating the mechanical vibration of the rigid racket on the lateral epicondyle in the face of a disrupted kinetic chain.

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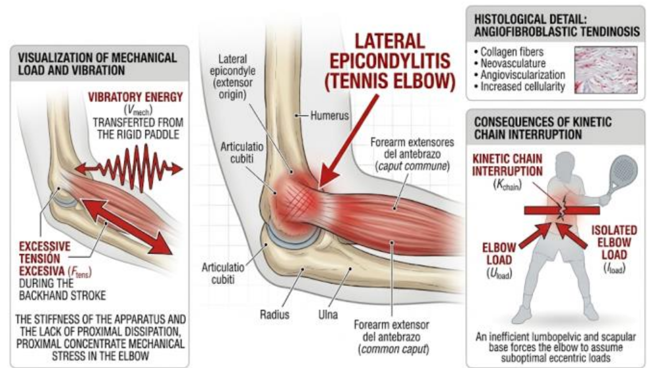

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Ankle Sprain: Sudden disruption of lumbopelvic and proprioceptive stability resulting in a loss of ligamentous integrity during explosive changes of direction, revealing a failure in connectivity with the ground.

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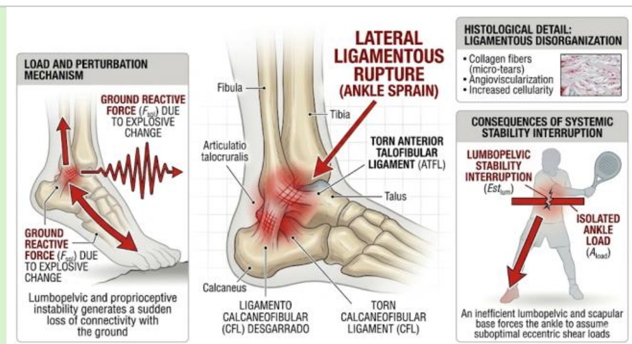

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Plantar Fasciitis: Fatigue inflammation at the base of the support system, derived from an inefficient distribution of ground reactive forces and over-exertion during the biomechanical propulsion phase.

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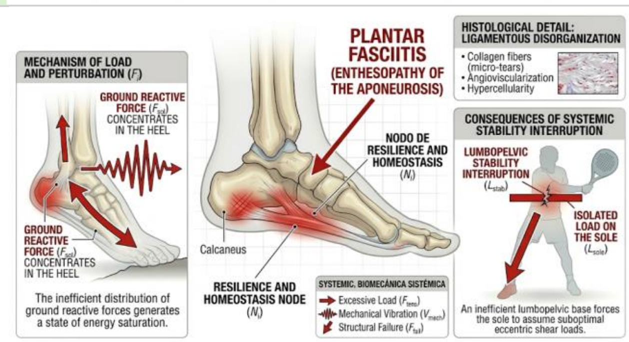

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Mechanical Lower Back Pain: A breakdown in the core's ability to transfer energy, occurring when the demand for powerful rotation overwhelms the stability of the lumbopelvic region. This overload triggers a pain signal, acting as a protective mechanism to stop the harmful movement.

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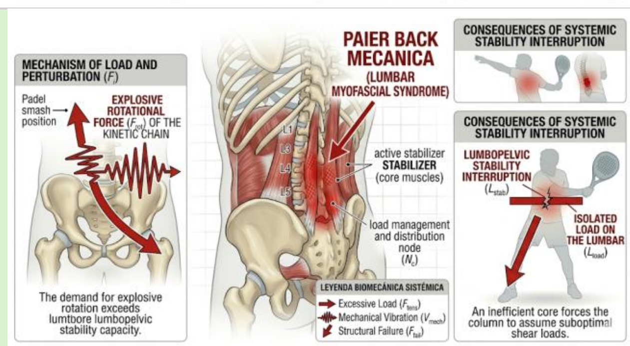

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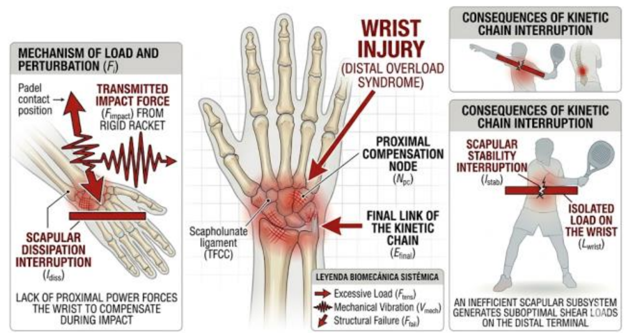
<table>
<tr><th>Systemic Concept and Definition</th><th>Scientific Visual Representation</th></tr>
<tr><td>Wrist Injury: The loss of homeostasis in the final segment of the kinetic chain typically results from motor compensation. This compensation occurs when the proximal segments (the legs and trunk) fail to generate adequate power.</td><td>
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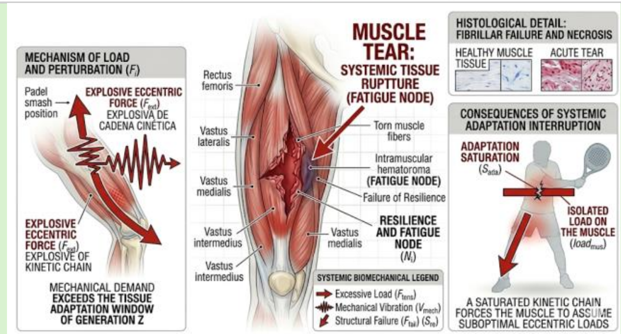
<tr><td>Muscle Tear: A muscle injury results from an eccentric demand that surpasses the tissue's elasticity limit and its speed of adaptation, typically occurring when the system is already fatigued.</td><td>
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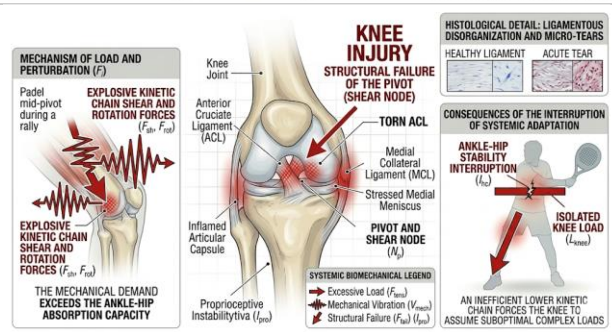
<tr><td>Knee Injury: The pivotal point of the lower kinetic chain failed structurally. This failure resulted from its inability to manage shear and rotational forces, which were insufficiently absorbed or mitigated by the ankle-hip subsystem.</td><td>
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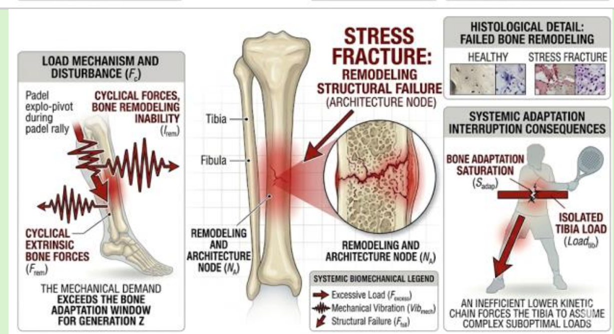
<tr><td>Stress Fracture: The loss of architectural integrity in the tissue is the ultimate result of a suboptimal bone adaptation velocity. This occurs when persistent cyclic loading surpasses the tissue's capacity for remodeling.</td><td>
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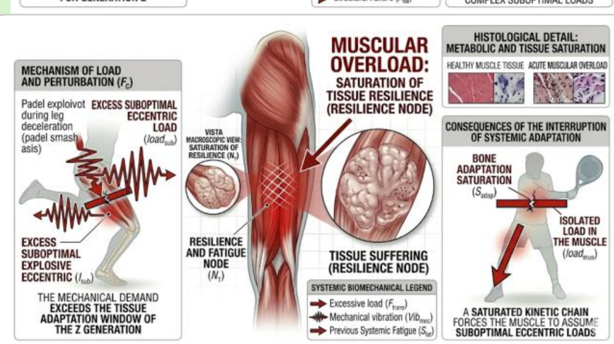
<tr><td>Muscle Overload: Muscle tissue is in a state of energy saturation, serving as a low-intensity, early warning sign. This signals that the system's capacity for resilience has been depleted, and a return to homeostasis is necessary.</td><td>
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2.1 Vulnerability Mapping

The build-up of tension in proximal zones (shoulder and lower back) and distal zones (elbow and ankle) shows that stress is not spread evenly; instead, it piles up in joints that act as compensatory "hinges" due to underlying technical faults. This is not just a lack of muscle strength, is a problem of mechanical resonance (when a physical system is hit by an external force that matches the system's own natural vibration frequency). If the neuromuscular system cannot dampen these vibrations quickly enough, the leftover energy moves into the soft tissues, speeding up the process of material fatigue in the tendon. For this reason, we created a vulnerability or critical risk map that changes significantly depending on the player's strategy and posture during each point. As the epidemiological analysis suggests, the distribution of these loads is not random (Castillo-Lozano, 2017) and has well-identified points of case concentration, severely focusing on the elbow (55 cases) and the ankle (45 cases) (see Figure 1).

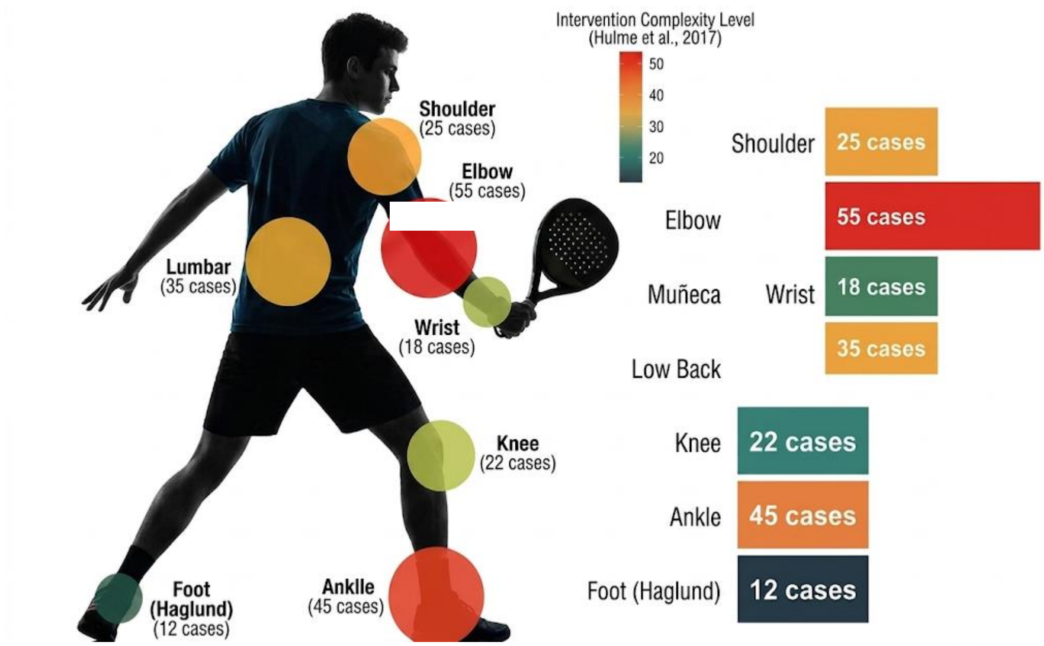

Figure 1. Localization of injury foci and prodromal states.

Given that padel is a kinetic sport (Ellenbecker & Aoki, 2020), it is common for a single athlete to experience multiple, simultaneous systemic failures. Consequently, high reported values represent the total injury load and accumulated recovery effort, rather than the raw count of affected individuals (table 1 is included to provide an initial understanding of fundamental differences in injury on each body part).

In Generation Z athletes, overuse injuries are the result of a complex interaction between biomechanical factors and a failure in systemic feedback (Paterno et al., 2013; Domínguez-Ríos & López-Santillán, 2016). While the body signals impending structural failure through prodromal pain (e.g., stiffness or mild inflammation), the core problem is a "cognitive dissociation" from this warning. The athlete, often driven by a heavy reliance on external metrics (Dudley et al., 2023) like tracking statistics via smart devices, continues to introduce explosive loads into an already destabilized structure. This ignorance of bio-feedback disrupts the player's self-regulation capacity, transforming a subtle prodromal signal into a severe structural failure. This creates a critical contradiction, when the athlete possesses more external data (on performance) yet listens less to their own biology, resulting in a self-forced and dangerous sensory silence.

3 The Interdependence of Micro-Detail: The Cascade Effect

The body's systems are profoundly interconnected, meaning a weak link in one area can ripple through and ultimately collapse the entire biomechanical network. If the lumbopelvic region, the body's central engine, lacks stability, the twisting forces of padel overwhelm the lumbar spine, triggering a chain of compression (Cook et al., 2014). Similarly, an inefficient shoulder blade forces the rotator cuff to assume excessive load, inevitably leading to joint compression and spreading damage to the elbow and wrist. In both scenarios, we witness the Cascade Effect, where a single initial failure sparks an inevitable, sequential chain reaction. Understanding this complexity must fundamentally reshape the Return to Sport (RTS) decision, which is a continuous, multifaceted process. Medical and training professionals must abandon fixed, linear recovery timelines (Yung, 2023) and use clinical reasoning rooted in complex systems theory to weigh every biological, functional, and psychological factor (Dines et al., 2015). The goal of RTS is not merely to fix a single joint but to restore the body's underlying movement patterns (see Table 2).

Table 2. Analysis of functional subsystems and interconnected systemic model.

Functional Subsystem (Node)	Physiological Mechanism (Green Flow)	Failure Dynamics (Red Flow)	Pathological Manifestation (Tension Point)	Physical Shielding Justification (Intervention)
I. Lumbopelvic (Transfer Core)	Trans-diagonal generation and distribution of torque from the lower limb toward the upper limb.	Loss of systemic core rigidity, causing shear in lumbar facets (mechanical stress occurring when parallel and opposite forces act on a material in opposite directions).	Mechanical Lower Back Pain: Impingement due to central instability.	Lumbopelvic stabilization to restore the central oscillator (functional rhythm)
II. Upper Limb (Dissipative Terminal)	Dissipation of residual impact energy through a stable scapular base.	Trunk Disconnection: An inefficient scapula forces the rotator cuff to generate force rather than direct it.	Epicondylitis / Impingement: Overload due to proximal compensation and ergonomic error (grip).	Strengthening through eccentric exercise and refining the racket-to-hand connection.
III. Support (Base Interface)	Impact absorption and stabilization during changes in direction.	Closed Friction Loop: Restriction of micro-calcaneal movement due to excessive adherence.	Haglund / Sprain: Harmful bone restructuring and increased susceptibility of ligaments to damage.	Enhancing joint mobility and critically selecting the appropriate footwear and court surface.

4 Methodological Design and Ecosystem Quantification

Our methodology employs an observational and analytical design specifically engineered to quantify the systemic interrelationships within a complex system, viewing injury not as a stochastic event but as the result of systemic desynchronization. This approach re-engineers' empirical methods to measure non-linear dynamics, marking a shift from traditional, reductionist models. The analysis utilized a sample of 27 individuals (Figure 2), focusing on the frequency and severity of events (Garrick, 1977) across three distinct stages: identification, injury, and recovery complexity. The sample was composed from Anahuac University students and was selected using a non-probabilistic convenience sampling method. Inclusion criteria focused on active Padel players within the Generation Z cohort (born after 1997) with a history of at least one overuse injury or ailments in the preceding year.

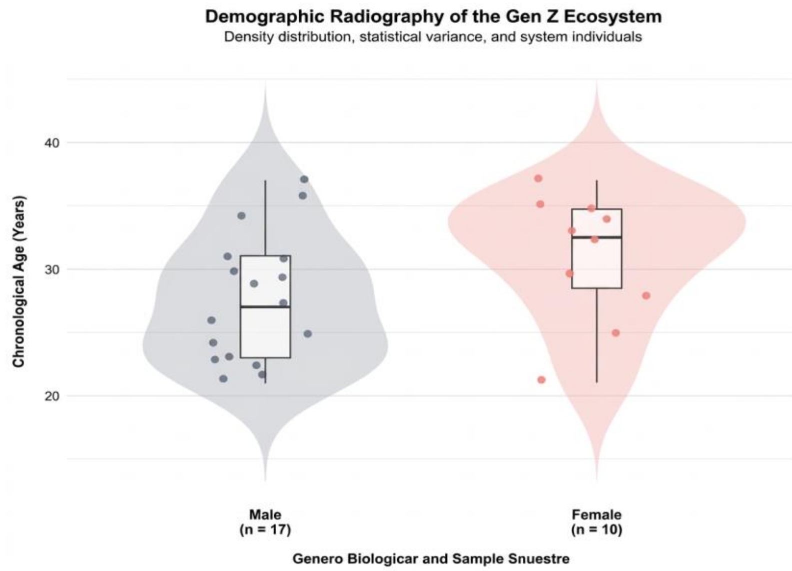

Figure 2. Demographic Radiography of the sample

Data collection was structured using a three-phase interrelationship matrix that tracks the transition from structural integrity to therapeutic complexity and integrates Heart Rate Variability (HRV) monitoring as a metric for neural fatigue (Ernst, 2017):

- Phase I: Identification of the Structural State. A categorical measurement classifying the athlete's integrity as "No Injury," "Prodrome" (mild inflammation), or "Injury" (structural collapse).
- Phase II: Magnitude of the Failure. Quantifies tissue damage severity using a continuous normalized 0-to-10 scale (results: 1.90 to 6.50), later categorized into "Mild (1-3)" and "Moderate (4-6)" levels.
- Phase III: Complexity of the Mediation. Determines the therapeutic effort required for recovery by evaluating the athlete's usage of eleven pre-defined intervention vectors.

The methodological framework supports the *Physical Shielding* model by establishing that recovery from systemic failure requires a complete architectural redesign, moving from isolated treatment to holistic habilitation. This protective strategy is constructed through interventions that significantly enhance muscle readiness and dynamic balance necessary for athletic performance, as evidenced by related training protocols (Tsartsapakis et al., 2025). Operationally, the approach involves tailoring intervention vectors: focused eccentric work is used to enhance tissue tolerance, while intelligent adjustments to external mediators reduce entropic input. This method ensures players gain the long-term ability to naturally resist severe biomechanical stress by fostering an intuitive, self-aware connection to their integrated biology.

Subsequent analytical processing employs dynamic flow diagrams, such as the Sankey Diagram, to empirically demonstrate the Cascade Effect. This visualization provides quantifiable evidence that neglecting the early, subtle prodromal stage inevitably leads to interventions of higher complexity and cost. Our quantification strategy is thus directly tailored to prove our hypothesis within the framework of Complex Systems Theory.

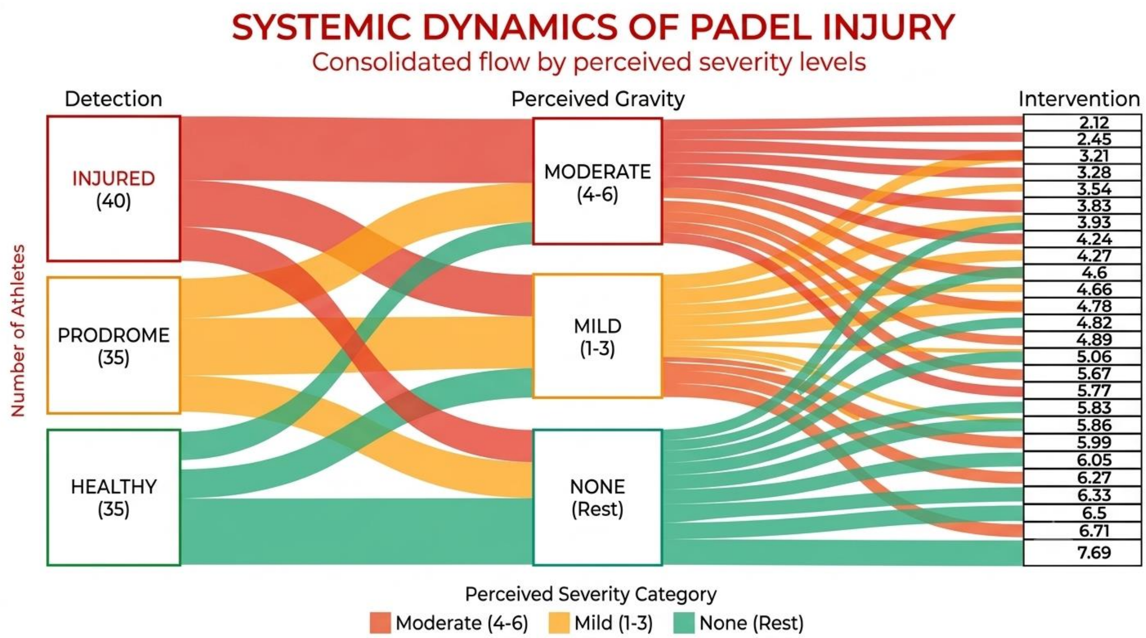

Figure 3. Sankey Diagram

This Sankey diagram provides a consolidated illustration of the athlete flow through different critical stages of joint health, based on perceived severity levels. The visualization is divided into three main temporal milestones: Detection, Severity Level, and Intervention. Main Findings:

Starting Point (Detection): The diagram begins with the initial categorization of athletes at the Detection point. A clear distinction is observed between those reporting a manifest Injury and those in a Prodrome state - a critical early warning phase. A third, sizeable group is classified as initially Injury-Free.

Flow Evolution (Severity Level): As athletes progress toward the Severity Level stage, the colored flows reveal interesting patterns of symptom progression and regression:

- Moderate (4-6) - (Red): A large proportion of athletes in this intermediate severity category originates from the initial Injury-Free group. This suggests the existence of loading mechanisms or play patterns that can lead to rapid development of moderate symptoms, or that initial symptoms went undetected by the "Injury/Prodrome" classification. The manifest Injury group also significantly feeds this category.
- Mild (1-3) - (Yellow): This flow primarily originates from the Prodrome phase group, validating that prodromal symptoms often escalate to a mild level. It also receives smaller flows from "Injury" and "Injury-Free."
- Null/Rest - (Light Green): Representing the optimal or recovery state, this is the most massive flow and predominantly comes from the Injury-Free group. However, it also absorbs athletes who reported "Injury" and "Prodrome," indicating successful recovery trajectories or, in some cases, a temporary state of rest prior to intervention.

Final Point (Intervention): The Intervention stage shows a wide dispersion of flows. Most "Moderate" and "Mild" gravity flows (red and yellow) move toward the bottom of the axis, which could be interpreted as a need for more intensive or specialized interventions. Conversely, the vast majority of "Null/Rest" flows (light green) remain in the upper and middle sections, suggesting trajectories that required less intervention or remained stable in their non-injured state.

When looking at the demographic data, we confirmed distinct patterns (Muñoz et al., 2022): for men, the most common issues are shoulder tendinitis, lower back pain, and ankle sprains. In contrast, women show a high rate of epicondylitis (tennis elbow) and lower back pain. This suggests that gender differences in impact absorption and hitting mechanics must be considered (see Figure 4).

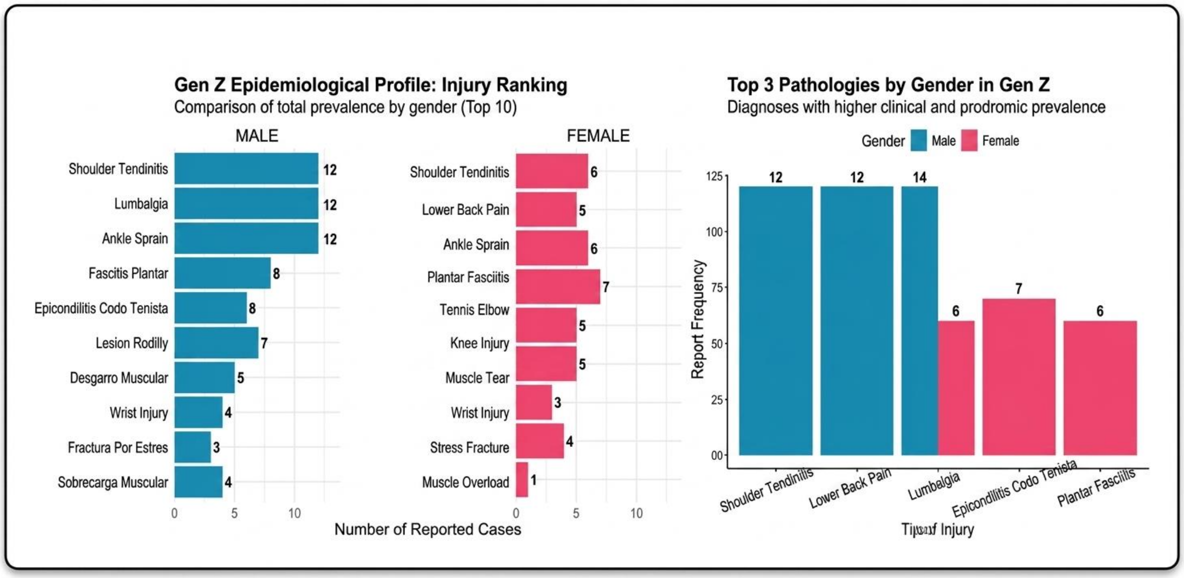

Figure 4. Comparison of total prevalence by gender (from Top 10 to Top 3)

4.1 The Paradox of Quantification and Failure Dynamics

The comparative analysis between the consolidated injury and the prodromal state reveals the true condition of the Generation Z biomechanical system. While a confirmed injury represents a total failure in the athlete's ability to function, the prodrome (the early warning stage) is like noise in the system, signaling that the internal balance is already compromised (Bittencourt et al., 2016). Our morbidity data shows that common overuse issues, such as tennis elbow (epicondylitis) and lower back pain, often start as clear prodromal warnings before developing into severe structural failures because the player ignores these signals and loses their ability to self-regulate (see Figure 5). When early intervention is neglected, the body is forced into harmful compensatory movements, quickly leading to functional collapse (Cifuentes, et al, 2024).

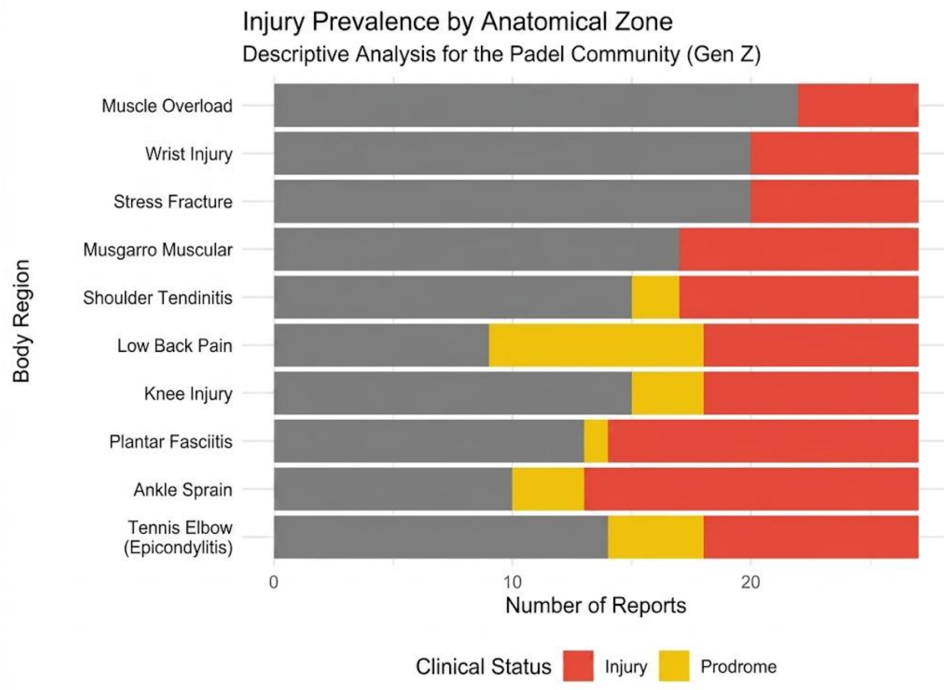

Figure 5. Proportion of clinical states (Prodrome vs. Injury) by body region.

The visualization divides the sample into three operational states that define the athlete's integrity: the gray area represents the system's functional reserve (biological safety margin); colors progressing illustrate the gradual decay of biomechanical health, where the yellow segment, signifying the prodromal phase, acts as a critical window of opportunity. Recognizing this warning allows the player to initiate Physical Shielding, which we define not as a simple exercise routine, but as a deliberate restoration of the body's natural tensegrity. In the high-stakes environment of padel, the player's integrity depends on a seamless conversation between the stabilizing core and the expressive movement of the limbs. This approach suggests that the health of every joint is tied to how effectively energy flows diagonally across the body. By cultivating systemic stiffness through controlled eccentric loading, we expand the body's resilience margin and create a biological buffer that absorbs vibrations and reactive forces of the court, neutralizing stress before it can harden into structural damage (Priego, et al., 2016).

5. The Architectural Design of Homeostasis: Integral Physical Shielding

The resolution of a systemic failure is not achieved by treating the isolated symptom, but by restructuring the system in its entirety. Therefore, a transition toward a holistic pre-habilitation model, Physical Shielding, is proposed (Figure 6). Shielding is defined not merely as muscle strength, but as systemic resilience and the capacity to absorb perturbations - ensuring the system dissipates residual energy before reaching the threshold of plastic deformation. From a clinical perspective, its success lies in the ability to intervene in the prodromal space - the intermediate stage where biological noise signals a loss of homeostasis, but a consolidated macrostructural injury does not yet exist. By monitoring subtle warning signs like micro-movement restriction in the support subsystem or scapular dyskinesia in the upper limb, this proactive protocol acts as a defensive barrier that mitigates systemic entropy. This approach transforms the organism's response to the repetitive stress of modern padel (Sánchez-Alcaraz et al., 2023), replacing pathological compensations with efficient load distribution, thereby ensuring the long-term sustainability of athletic performance in the Gen Z cohort.

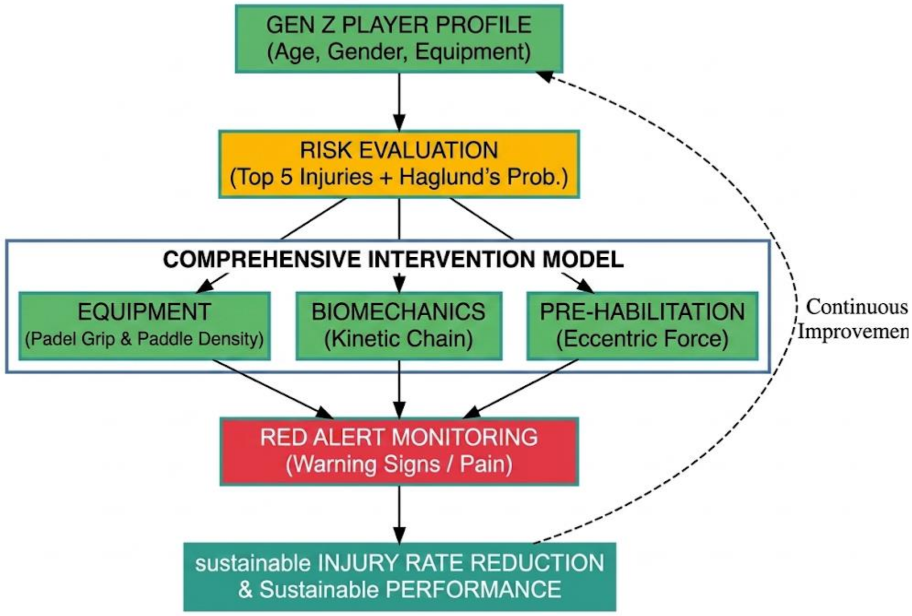

Figure 6. Clinical decision algorithm: Risk assessment, multi-layer intervention (Equipment, Biomechanics, Pre-habilitation), and continuous improvement monitoring.

The clinical decision algorithm establishes a mediation network. It connects risk identification with ergonomic and conditioning actions to ensure biomechanical sustainability.

5.1. The Trinomial: Equipment, Biomechanics, and Tissue Shielding

The first level of immediate action (Table 3) addresses racket density and grip thickness. In Gen Z, where ball speed is higher than in previous generations, parasitic vibration is the primary vector of entropy in the upper limb.

Intervention: Clinical shielding prescribes the use of elastomers (EVA Soft) and grip adjustment to avoid the excessive instinctive grasping performed by the player on the handle. This is complemented by eccentric strength exercises (braking against an external load higher than the force produced) for the wrist extensors, increasing tendon tolerance to sudden traction during the smash.

5.1.1. Proximal Stabilization and Trans-diagonal Transfer

Modern padel clinical data reveal that Lower Back Pain and Shoulder Tendinitis are not isolated pathologies, but failures in the kinetic chain. The close linear relationship observed between lower back pain and shoulder tendinitis (Figure 7) evidences a critical functional dependence within the padel player's biomechanical system.

From a network physiology perspective, the lumbar zone acts as the central node for stabilization and energy (torque) transfer from the lower limbs toward the hitting arm. When this "support subsystem" presents dysfunction or pain (lower back pain), the system

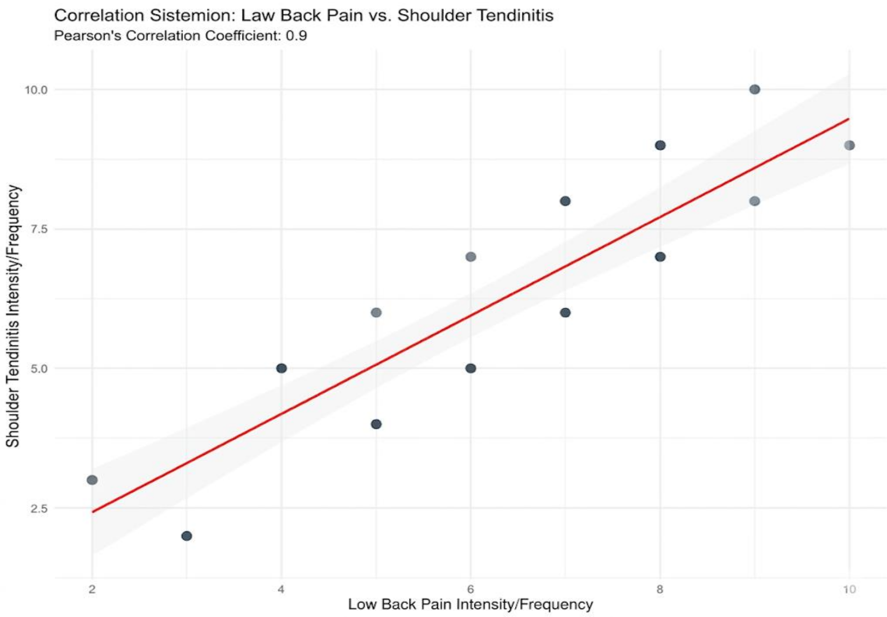

Figure 7. Correlation Map: Lower Back Pain – Shoulder Tendinitis

Systemic Action**:** In the face of a medium-to-high alert in the shoulder, the protocol is not limited to the rotator cuff; it demands the optimization of hip rotation. An unstable lumbopelvic core forces the shoulder to generate an acceleration for which it is not structurally designed. Shielding, therefore, integrates core stability and thoracic mobility to "release" the peripheral joints.

5.1.2. The Support Subsystem: From Foot to Ankle

The high prevalence of plantar fasciitis and Haglund's deformity in Generation Z should not be understood as an isolated pathology, but as a failure in the systemic management of braking forces and explosive changes of direction. From a biomechanical perspective, the foot acts as the primary energy transducer; when functional entropy exists within this subsystem, the athlete's tensegrity is disrupted.

As observed in the correlation heat map (Figure 8), there is a strong positive correlation between game volume and tissue stress in the calcaneus. This indicates that as the intensity of kinetic loads increases without adequate Physical Shielding, the bone and fascial structures tend to develop prodromal states (silent inflammation) that culminate in chronic injuries. Therefore, ankle stability depends not only on its anatomy but on its capacity to dissipate mechanical energy before it saturates the system.

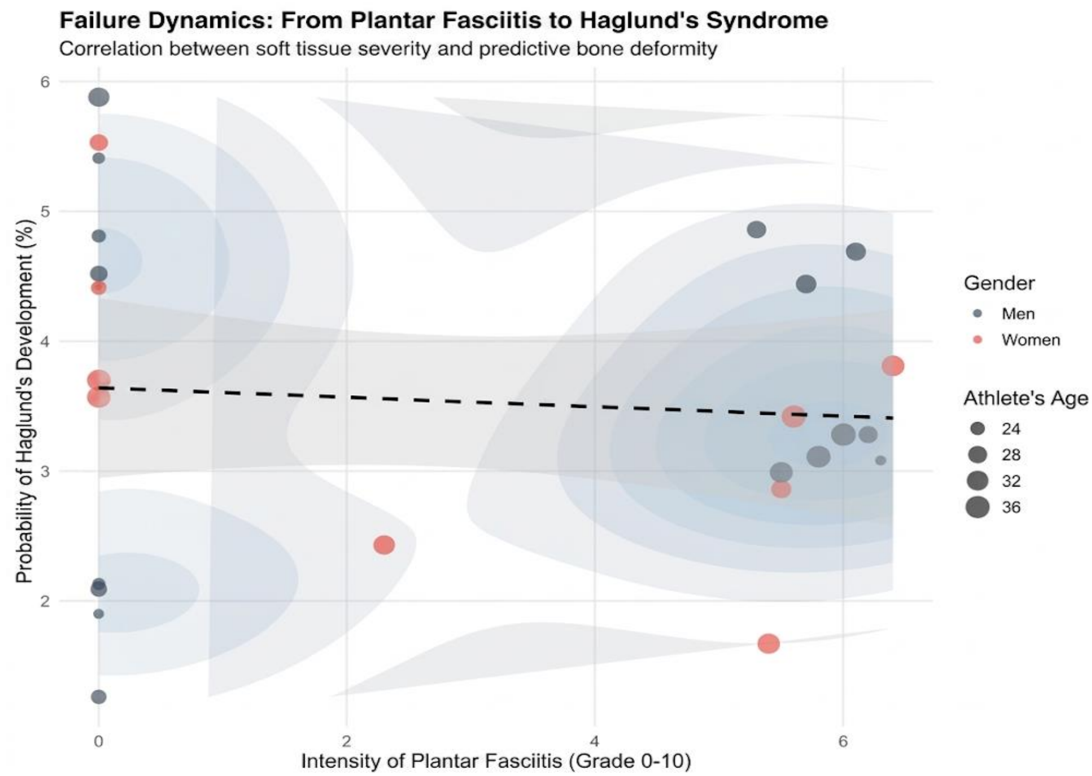

Figure 8. Correlation Map: Haglund's Deformity – Plantar Fasciitis

Ergonomic Adjustment: Clinical recommendations include the use of footwear with lateral reinforcement and an ergonomic drop. However, true "shielding" occurs through myofascial release and the strengthening of the posterior tibialis muscle, which acts as the passive stabilizer of the medial arch, preventing foot collapse under fatigue.

5.1.3. The Cognitive Dimension and Heart Rate Variability

Finally, the protocol in action recognizes that neural fatigue precedes mechanical failure. Monitoring HRV is integrated as a systemic "red alert" metric. Clinical application instructs the player in "biological listening," differentiating adaptive training soreness from injurious prodromal pain, while encouraging digital disconnection to optimize the REM phase and collagen synthesis.

Table 3. Preventive actions and technical adjustments based on alert levels.

Dimension	Focus of Analysis	Preventive Action (Shielding)	Red Alert (Systemic Failure)	Additional Consideration (Gen Z / Pro)
Equipment	Racket Density and Grip	Use rackets with elastic cores (EVA Soft). Adjust grip thickness to avoid "clawing" the forearm.	Bothersome parasitic vibration in the epicondyle after off-center hits.	Evaluate racket balance (toward the handle) to reduce the moment of force on the wrist.
Biomechanics	Stroke Kinetic Chain	Optimize hip rotation and weight transfer from the support foot to release the elbow.	Piercing pain or loss of fine control at the moment of impact.	Shoulder prodromes are often a sign of an excessively "cocked" smash technique.
Physical Prep	Pre-habilitation / Core	Eccentric strength work on tendons and lumbopelvic (Core) stability 2-3 times per week.	Persistent morning stiffness or sudden muscle weakness during competition.	Integrate plantar proprioception exercises to shield the ankle against Haglund's deformity.

Recovery	Load Management	Respect 48h supercompensation periods after high-intensity sessions or tournaments.	Chronic fatigue that does not remit after restorative sleep or systemic irritability.	Monitor HRV as a metric for neural fatigue.
Nutrition	Structural Supplementation	Magnesium, Collagen, and Vitamin C protocol to promote connective tissue synthesis.	Recurrent cramps, fasciculations, or a sensation of heaviness in lower limbs.	Ensure hydration rich in electrolytes to maintain the turgidity of intervertebral discs.
Cognitive	Biological Listening	Bio-feedback training to differentiate "training soreness" from "prodromal pain."	Voluntary ignorance of physical signals to comply with external metrics (watches/rankings).	Encourage post-match digital disconnection to improve the quality of the REM recovery phase.
Pathology (Failure Node)	**Alert Level**	**Key Shielding Exercise (Therapeutic Focus)**	**Technical / Ergonomic Adjustment (Biomechanical Focus)**	**Additional Shielding Consideration**
Elbow Epicondylitis	Very High	Eccentric strengthening of wrist extensors with emphasis on the negative phase.	Increase grip thickness to reduce stress on the epicondylar musculature.	Review string tension; high tension increases vibration transmission.
Ankle Sprain	High	Single-leg balance on unstable surfaces, integrating the technical hitting motion.	Footwear with lateral reinforcement and sole designed for controlled sliding on the court.	Strengthening of the posterior tibialis muscle for passive stabilization of the medial arch.
Shoulder Tendinitis	Medium-High	Thoracic mobility exercises and strengthening of the external rotators (rotator cuff).	Optimize the stroke preparation phase to avoid sudden and injurious accelerations.	Evaluate pectoralis minor flexibility to prevent scapular protraction.
Lower Back Pain	Medium	Core Stability with an emphasis on lumbopelvic control.	Correction of knee flexion technique: prioritize the knee joint over the spine.	Promote hip mobility to reduce the transfer of rotational stress to the lumbar zone.
Fasciitis / Haglund	Medium	Plantar myofascial release and controlled stretching of the Achilles complex.	Use of footwear with an ergonomic drop; avoid excessively flat shoes.	Consider the use of custom plantar orthotics for the dissipation of impact forces.

6. Discussions

The most disruptive finding of this analysis is the obsolescence of the reactive approach. While traditional medicine centers its success on resolving "consolidated failure," the data suggest that the true clinical battlefield lies within the prodromal state. To ignore subtle signals of homeostatic loss while waiting for structural rupture is, under current performance standards, a clinically and professionally unsound approach.

To quantify systemic health and ensure reproducibility, the model integrates both external and internal metrics based on key monitoring variables. These include Neural Fatigue (Heart Rate Variability, or HRV, to track the body's self-regulatory capacity), Motor Pattern Integrity (Functional Movement Screens to re-educate the motor pattern), Biological Feedback (bio-feedback training to differentiate prodromal pain from adaptive soreness), and Tension Points (continuous assessment of localized signs like micro-movement restriction or scapular dyskinesia to identify subtle homeostatic loss).

To validate the model's effectiveness, future empirical studies should apply the Ecosystem Quantification methodology and test the hypothesis that Physical Shielding reduces therapeutic complexity. The primary outcome variables for evaluation would be:

- Reduction in Prodromal State Frequency (Phase I): Quantify the percentage reduction in the incidence of "Prodrome" reports (mild inflammation/biological noise) within the cohort.

- Decrease in Complexity of Mediation (Phase III): Measure the reduction in the total number of necessary intervention vectors (out of the eleven tracked vectors) required for full Return to Sport (RTS). A successful protocol would demonstrate that by intervening early in the prodromal phase, the subsequent severity (Phase II) and therapeutic complexity (Phase III) are mathematically and significantly reduced, proving its capacity to mitigate the Cascade Effect.

Technology as a Biomechanical Extension: This highlights the need to redefine equipment; the racket and footwear must not be treated as external variables, but as load modulators. The study demonstrates that poorly parameterized equipment can act as a "source of deleterious mechanical stress," breaking the kinetic chain even in athletes with refined technique. The integration of ergonomics into clinical diagnosis is now an undeniable necessity. Finally, the results compel health professionals to distrust the "geography of pain." The validation of the cascade effect redefines differential diagnosis; we propose that treating the symptom without correcting the origin node is not a cure, but a postponement of chronicity. The future of athletic longevity resides in understanding that, in the human body, the problem is rarely located where the "cry of pain" manifests.

7. Conclusions

The research conducted confirms that injury phenomenology in contemporary padel is not a stochastic event (random, unpredictable phenomena), but rather the result of systemic desynchronization. By applying Complex Systems Theory, we conclude that the health of the Gen Z athlete does not depend on the isolated integrity of their joints, but on the quality of the connectivity between their biomechanical, ergonomic, and neurocognitive nodes.

The "Physical Shielding" model is thus established as a structural intervention philosophy aimed at equipping players with an adaptive resilience that allows them to navigate the high demands of professional padel without compromising their long-term structural and functional integrity. Ultimately, the sustainability of this sport in new generations will depend on migrating from a culture of reaction toward one of systemic metacognition.

Physical Shielding is structured as a dynamic, three-layer intervention, deliberately moving away from static training programs. Our design specifies the protocol's components, criteria for progression, and variables for objective monitoring, allowing it to transition from a theoretical proposal to a reproducible, pre-habilitation model.

Components of the Physical Shielding Protocol (Three Layers):

- Ergonomic Regulation (Artifact Adjustment): Direct, immediate action on technological mediators by calibrating the racket and optimizing grip density to actively reduce parasitic mechanical vibration before it enters the human tissue.
- Expansion of Absorption Capacity (The Subject): Focuses on tissue quality and resilience, utilizing eccentric and proprioceptive stimuli. The goal is to enhance the system's ability to absorb elastic energy without reaching the threshold of plastic deformation or structural failure.

The application of Physical Shielding should not be understood as a static recipe, but as a dynamic response to the biomechanical interface between the athlete, their equipment, and the game load. Based on the epidemiology collected in this Gen Z cohort, the protocol unfolds in a decision matrix that prioritizes the neutralization of "red alerts" before they consolidate into structural failure.

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