

Heart Rate Monitoring for Musculoskeletal Injury Risk Detection in Padel Sport: A Literature Review

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ABSTRACT

Padel is a racket-based sport that involves frequent high-intensity exertions, placing substantial demands on the cardiovascular and musculoskeletal systems of participants. Tracking physiological indicators like heart rate (HR) and heart rate variability (HRV) has emerged as a crucial method for evaluating training load, fatigue levels, and strategies to prevent injuries. This review sought to examine the significance of HR and HRV in detecting initial indicators of fatigue and potential injury risks among padel players. Out of 25 articles reviewed, five studies specifically pertaining to padel were selected for inclusion. The evidence indicated that athletes generally maintain HR at 70-85% of their maximum heart rate (HRmax) during matches, signifying intense intermittent activity. Additionally, a notable reduction in HRV post-match was observed, pointing to autonomic dysfunction and built-up fatigue. These results imply that ongoing HR and HRV monitoring, especially via wearable devices, offers a non-invasive and effective means to measure internal load, identify early physiological strain, and bolster injury prevention efforts. Incorporating HR-based assessments into training regimens allows coaches and sports experts to fine-tune workloads, oversee recovery processes, and reduce the incidence of overuse injuries, thereby improving performance and extending athletes' careers in padel.

Keywords: padel; sport; fatigue; musculoskeletal injury; heart rate

INTRODUCTION

This Padel was one of the most popular sports in Spain in the 1970s, and today its popularity has spread rapidly throughout the world. This sport is played by two players on a synthetic court surrounded by glass with a metal net (20x10 meters). Additionally, it is an intermittent high-intensity sport involving high-frequency exercises of low intensity [1]. According to the International Padel Federation (FIP), nearly 30 million amateur players play padel regularly (once a week). More than 59% of players come from Europe, a region much larger than South America, Asia, and other regions. Although 40% of padel players are women, most amateur players are still men (60%) [2].

The rise in popularity of padel has had a positive impact. This is due to a growing trend of increasing the subjective well-being and social engagement for

players and there is an increase in the number of licenses issued by the federation to professional players [3,4]. Despite this, padel demands explosive, repetitive movements and rapid direction changes. Consequently, the musculoskeletal system is put under considerable mechanical stress. According to a recent systematic review, 3 out of 1,000 hours of padel training and 8 out of 1,000 hours of padel competition resulted in injuries. Injuries in padel are estimated to constitute 40-95% of reported cases [5].

The rising appeal and rigorous physical requirements of padel emphasize the value of promptly detecting physiological strain and the potential for overuse to enhance performance and avert injuries. Monitoring heart rate (HR) and heart rate variability (HRV) has proven to be a valuable approach for achieving this goal [6]. Earlier studies have confirmed that HR serves as a reliable and unbiased measure for assessing and

tracking physical effort in exercise [7]. Moreover, variations in HR and declines in HRV are frequently linked to heightened fatigue, prolonged recovery periods, and an elevated risk of overuse injuries in numerous athletic fields [8].

While multiple investigations have explored HR and HRV responses in padel competitions, only a limited number have explicitly connected these physiological indicators to the risk of musculoskeletal injuries. The majority of current research is primarily observational and fails to combine HR, HRV, and external load data, thereby constraining their ability to predict and prevent issues. Consequently, this review seeks to consolidate existing findings on HR monitoring among padel athletes to evaluate its utility as a non-invasive method for spotting early signs of musculoskeletal injury risk and to propose avenues for future studies that merge physiological and biomechanical tracking systems.

METHODS

A comprehensive examination of the existing literature was undertaken to assess the utility of heart rate (HR) and heart rate variability (HRV) monitoring in spotting the potential for musculoskeletal injuries among padel players. An initial collection of 25 studies was obtained through searches across PubMed, Scopus, and ScienceDirect, utilizing the keywords padel, sport, fatigue, musculoskeletal injury, and heart rate. Inclusion criteria were: (1) original research on HR or HRV in padel or related racket sports; (2) outcomes related to physiological load, fatigue, or injury; and (3) studies published in English between 2015 and 2025.

After screening titles, abstracts, and full texts, 5 studies met the criteria and were included for synthesis. Each selected paper was extracted for author, year, study design, population/sample, HR-related variables, main outcomes, conclusions, strengths, and limitations. These data were organized into a summary table (Table 1) and thematically analyzed to identify how HR and HRV relate to physiological stress and potential injury mechanisms in padel.

RESULT AND DISCUSSION

Heart Rate Dynamics in Padel Performance

The resting human heart rate typically ranges from 60 to 100 beats per minute (bpm) in healthy adults [9]. However, large-scale population studies have provided more specific reference values. According to Persson et al. (2024), the daily average ambulatory heart rate (24-hour ECG) 2.5–97.5 percentile range was 57–90 bpm for men and 61–92 bpm for women in a healthy middle-aged population. Abnormally high or low HR values may indicate cardiovascular imbalance or potential health issues. Meanwhile, studies have shown that during matches, padel players reach average HR values of 143.63 ± 12.17 bpm [7].

Heart rate during exercise indicates the body's physiological reaction to the level and length of

physical effort. Padel, an intermittent sport featuring shifts between intense and less demanding phases, triggers a fluctuating cardiovascular adaptation. Multiple investigations have indicated that in padel games, athletes' HR generally reaches an average of 140–160 beats per minute, equating to roughly 70–80% of their maximum heart rate (HR_{max}). This classifies padel as a moderate-to-high intensity endeavor [10]. Likewise, recent studies have shown that elite padel competitors sustain average HR around 70–80% of HR_{max} throughout matches [11]. These observations imply that success in padel demands not just technical and strategic abilities, but also significant aerobic stamina to maintain output during extended exchanges and full games. Consequently, tracking HR in padel is crucial, as it quantifies the internal workload and the bodily strain from physical activity [12]. Additionally, HR evaluation helps in structuring training phases to boost VO₂max, build endurance, and improve recovery processes [13].

Epidemiology of Musculoskeletal Injury in Padel Players

Musculoskeletal injuries represent a primary reason for disruptions in sports participation, affecting both recreational and elite athletes [14, 15]. Approximately 30 to 50 percent of injuries sustained during sports activities involve soft tissues [16]. Overtraining injuries occur when the intensity or duration of training exceeds the body's capacity for recovery, resulting in physiological and biomechanical stress. This mismatch frequently contributes to exhaustion, reduced performance, and a heightened susceptibility to musculoskeletal harm [17, 18, 19]. Injuries associated with padel predominantly affect two joints: the knees, which are strained by frequent directional shifts, and the shoulders, which endure rapid and repeated ball impacts during matches [5]. The primary anatomical elements impacted include muscles, tendons, joints, and bones, with clinical manifestations varying from minor muscle tension to more severe conditions like tendinopathies, stress fractures, and chronic compartment syndromes [20]. A survey involving 800 padel participants revealed that elbow tendinopathy is the most prevalent upper limb condition, though the bulk of musculoskeletal injuries were noted in the lower limbs, particularly the knee joint [21]. Consistent with these findings, a retrospective cross-sectional study of 36 players who experienced 44 musculoskeletal injuries revealed that lower leg injury was the most prevalent among World Padel Tour 2021 players [22]. Moreover, a cross-sectional study of 130 youth athletes revealed that acute and overuse musculoskeletal injuries were significantly linked to reduced physical and mental well-being, highlighting a considerable negative impact on overall health [23].

Mechanism and Pathophysiology of Musculoskeletal Injury in Padel Players

According to its cause, muscle injury is classified

into indirect and direct [24]. Indirect injuries occur without any physical contact and hence may be caused by structural damage (e.g., partial or complete muscle rupture), mechanical overload, or neurological disturbance. Direct injuries arise from impact, resulting in contusions or lacerations less commonly [25]. Usually referred to as “muscle tears”, indirect muscle injuries are more frequently identified in daily clinical practice and simultaneously serve as a great challenge in rehabilitation, as these injuries lack a decisive therapeutic strategy [26].

Although injuries may occur in various anatomic locations, the elbow was the most frequently affected site in padel players, with most injuries involving muscular or tendinous structures. Specifically, most of the reported pathological findings are lateral epicondylitis, known as lateral elbow tendinopathy or tennis elbow, as this sport requires repetitive overhead movements, eccentric contractions, and the racket design itself that intensified mechanical strain on the elbow [5]. In comparison with tennis, padel rackets are stringless, causing poorer tension regulation during strokes and augmenting strain on the elbow [27]. A marked difference is also noticed between expert and novice players. The latter are more prone to lateral epicondylitis since they strike the ball with a flexed wrist, causing progressive eccentric stress and micro-tearing to the common extensor tendon of the elbow, as compared to expert players who maintain a hyperextended wrist throughout backhand strokes [16, 28].

When a skeletal muscle is injured, three overlapping phases of healing occur: destruction, repair, and

remodeling [16]. After a musculoskeletal injury, inflammation acts as a vital physiological reaction, with the healing process overseen by the autonomic nervous system (ANS) [29]. Myofibril rupture, necrosis, hematoma formation, and infiltration of inflammatory cells to the injury site in the destruction phase is ensued by the repair and remodeling phase, which forms a connective scar tissue and regenerates vascular and neural supply. Finally, regenerated fibers mature, scar tissue reorganizes, and muscle function is gradually restored in the remodeling phase. Of important note, the ANS plays a vital role in controlling blood circulation, enabling the transport of metabolic substances, and managing the release of neurotransmitters crucial for mechanotransduction within injured tissues. Thus, as tissue injury or active repair demands an elevated autonomic response marked by increased blood flow and heightened inflammatory neuromodulators, such variations in ANS activity can be identified through HRV metrics [30].

Heart Rate Variability and Musculoskeletal Injury Risk Association

The reviewed studies consistently show that heart rate and heart rate variability (HRV) serve as sensitive indicators of physiological stress and workload in padel players. Five studies were synthesized from 25 initially screened. All included papers examined HR or HRV as indicators of physiological load, fatigue, or autonomic balance, providing indirect evidence linking elevated cardiovascular strain with increased musculoskeletal injury risk in padel players (Table 1).

TABLE 1: Summary of Studies on Heart Rate Monitoring in Padel Players Related to Injury Risk.

Reference	Objective	Sample	Main Variables	Key Findings	Relevance to Injury Risk
31	To compare HRV before and after competitive match play.	16 male players, 21 matches.	HRV (Mean RR, SDNN, LnRMSSD, pNN50), in-match HR.	HRV indices significantly decreased post-match, indicating acute autonomic stress.	Reduced HRV signals fatigue accumulation and autonomic imbalance, potential precursors to overuse injury.
32	To evaluate short- and long-term HRV monitoring via wearable sensors.	20 male athletes (SCI), 6-month training.	HR and HRV indices (RMSSD, SDNN, LF/HF ratio).	HR and HRV effectively captured autonomic changes across training cycles.	Demonstrates wearable HR sensors can reliably detect internal stress, relevant for injury prevention protocols.
7	To analyze physiological responses and neuromuscular fatigue during padel.	52 amateur padel players.	HR (peak, average), HR zones, TRIMP, CMJ, RPE.	HR correlated with TRIMP and fatigue indicators; higher HR zone time linked to lower jump performance.	Confirms HR-based load tracking reflects fatigue status, supporting risk monitoring for musculoskeletal injury.
33	To assess the impact of playing style on physiological load.	24 players (offensive vs. defensive).	HR, playing style, match duration.	Offensive players displayed higher mean HR and energy expenditure.	Higher sustained HR in offensive play suggests elevated fatigue and injury susceptibility.

Reference	Objective	Sample	Main Variables	Key Findings	Relevance to Injury Risk
34	To describe physiological and metabolic profiles of elite padel players.	48 elite players (24 male, 24 female).	HR avg/peak, metabolic response, rally duration.	HR intensity differed by gender; sustained HR >80% HRmax during rallies.	High cardiovascular strain may increase risk of lower-limb and upper-limb injuries due to cumulative fatigue.

HR = Heart Rate; HRV = Heart Rate Variability; HRmax = Maximum Heart Rate; SDNN = Standard Deviation of Normal-to-Normal Intervals; LnRMSSD = Natural Logarithm of Root Mean Square of Successive Differences; pNN50 = Percentage of successive RR intervals differing by >50 ms; LF/HF = Low-frequency to High-frequency ratio (autonomic balance index); TRIMP = Training Impulse (internal training load); CMJ = Counter-Movement Jump; RPE = Rate of Perceived Exertion.

Heart rate variability (HRV) reflects short-term fluctuations in R-R intervals and is widely used as a non-invasive index of autonomic nervous system balance, particularly vagal-sympathetic interactions that modulate cardiovascular and pain responses. Systematic reviews on experimentally induced pain show that individuals with lower resting HRV and blunted vagal reactivity tend to report higher pain intensity and lower pain tolerance, suggesting that impaired autonomic flexibility may predispose to heightened nociception [35]. Early autonomic dysregulation, manifested as sustained reductions in HRV, could emerge before clinical symptoms of musculoskeletal overuse injuries, because the autonomic nervous system contributes to inflammatory control, tissue repair, and perception of fatigue [36]. In people with chronic musculoskeletal pain, a recent systematic review of exercise interventions reported consistently reduced baseline HRV and autonomic imbalance compared with pain-free controls, and suggested that exercise programs capable of restoring vagal activity might simultaneously improve pain and physical function, reinforcing HRV as a mechanistic biomarker linking autonomic function to musculoskeletal symptom burden [37].

Research from athletic groups further indicates a link between heart rate variability (HRV) patterns and the likelihood or occurrence of musculoskeletal injuries. A systematic review on HRV and sports injuries found that lower HRV levels and sympathetic-vagal imbalances are commonly seen in athletes dealing with fatigue, overreaching, or non-contact injuries, positioning HRV as a potential screening method for identifying emerging injury risks [38]. In the case of distance runners, Guthrie and Williams proposed that tracking HRV could offer an objective way to spot maladaptive reactions to training demands, thus pinpointing those at greater risk of overuse injuries prior to the onset of clinical signs [39]. Prospective findings from young sprint swimmers revealed that participants with poorer autonomic function, marked by diminished vagal-related HRV metrics over a 20-week training cycle, suffered a higher rate of time-loss injuries compared to those with stronger parasympathetic activity, implying that HRV assessments might aid in categorizing injury vulnerability in intense training settings [40]. More recently, a cohort investigation of semi-professional soccer players uncovered significant alterations in frequency-domain HRV indicators shortly following acute musculoskeletal

injuries, with some recovery upon resuming play, underscoring that such injuries coincide with temporary disruptions in autonomic control detectable via HRV tracking [41].

Taken together, these findings support a biologically plausible and increasingly well-documented link between HRV and musculoskeletal injury risk, while underscoring the need for sport- and task-specific prospective studies to determine clinically useful HRV-based thresholds and monitoring protocols in different athletic populations [38-41]. Heart rate variability (HRV) offers a more accurate depiction of the physiological state of healing tissues and their readiness to endure mechanical stress. Monitoring HRV responses can help identify overuse injuries early, guide rehabilitation planning, and refine return-to-sport protocols, ultimately protecting and supporting the recovery of injured tissues [42].

Future Research Prospects

Future studies should employ large, prospective cohorts with standardized HRV protocols and robust, sport-specific injury surveillance to clarify dose-response relationships between autonomic changes and musculoskeletal injury risk [36, 38, 40]. Randomized or cluster trials are needed to test whether HRV-guided load management actually reduces overuse and acute injuries compared with usual practice [43]. In parallel, integrative designs combining HRV with external load, pain/function scores, and tissue or inflammatory markers could determine whether HRV behaves as an early warning signal of maladaptation and support the development of simple, sport- and sex-specific decision rules for practical use by coaches and clinicians [37, 41].

Overall, the evidence supports HR monitoring as a non-invasive, cost-effective, and accessible strategy for detecting physiological precursors of musculoskeletal injury in padel. However, standardized HR thresholds, larger sample sizes, and validation across different competitive levels are still needed to translate these findings into applied sports medicine. While existing research validates the connection between cardiovascular strain and injury susceptibility, the area is constrained by limited sample sizes, inconsistent methodologies, and insufficient long-term verification. Upcoming investigations should establish uniform heart rate-based thresholds, integrate HRV with external training loads and

biomechanical data, and evaluate HRV-informed interventions for their role in lowering injury rates. Additionally, future research ought to create comprehensive models that incorporate HR metrics alongside biomechanical, neuromuscular, and recovery factors to facilitate tailored injury prevention strategies for padel athletes.

CONCLUSIONS

Monitoring heart rate and heart rate variability yields important information on physiological demands, fatigue levels, and recovery in padel players. Persistent increases in heart rate and declines in HRV signal autonomic disruptions that frequently precede musculoskeletal injuries, rendering these metrics effective as early alert systems. In summary, heart rate monitoring represents a practical and economical approach to improving performance and averting musculoskeletal injuries in padel.

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