



Digital Technologies Reshaping Performance and Recovery in Modern Sports

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Abstract. General Background: The global sports sector is undergoing rapid digital transformation driven by wearable sensors, analytics platforms, artificial intelligence, and immersive technologies. Specific Background: Elite and mid-tier sports organizations increasingly integrate real-time monitoring, virtual simulations, and data-based workload management into training, officiating, and rehabilitation systems. Knowledge Gap: Despite widespread adoption, comparative synthesis across team sports, individual sports, and e-sports—particularly regarding performance metrics, injury reduction rates, and cost structures—remains fragmented. Aims: This review synthesizes recent scholarly and industry evidence to examine adoption patterns, technological integration levels, recovery applications, and budgetary dimensions across sport categories. Results: Findings indicate reductions in overuse injuries (22%), improved early fatigue detection (~35%), shortened rehabilitation timelines (25%), and measurable gains in motor skill execution (~15%), alongside market growth projections exceeding USD 105 billion by 2033. Novelty: considerations within a unified cross The study integrates performance analytics, rehabilitation technologies, economic data, and ethical-sport analytical framework. Implications: Results underscore the need for balanced governance, equitable access models, and athlete-centered data policies to maintain competitive integrity while navigating accelerating technological expansion.

Keywords: Digital Sports Technology, Wearable Analytics, Injury Recovery Systems, Sports Data Governance, Performance Monitoring

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INTRODUCTION

Global sports have gravitated toward wearable sensors, real-time analytics platforms and virtual training solutions in search of competitive advantages and commercial opportunities. The pandemic sped up this digital migration even more as leagues tried to keep training, officiating quality, and fan engagement in somehow challenging settings. Many studies point out that success in today's sport is reliant on striking a balance between the best traditions of coaching and data-driven decision-making, while governing bodies of sport are introducing new regulations to govern technologies as varied as video assistant referees and remote concussion-monitoring devices. This review paper systematically summarizes important technology-driven sport research advancements, highlighting distinct strategies and outcomes in team versus individual sports, as well as in the fully virtual domain of e-sports. It investigates how data streams feed training loads, video and wearable feedback techniques, and how uptake both across its breadth and rapid speed matches places where organizations do so at evidence of a competitive or financial return. Attention is drawn not only to which sports are embedding technology most deeply, but also to how quickly others are closing the gap and the ways these tools enhance injury prevention and recovery [1,2].

1. RESEARCH QUESTIONS

In synthesizing recent data and trends, this paper seeks to answer five questions. The first relates to the level and type of tech adoption in sport, particularly examining how team sports, individual sports and e-sports compare. The second looks at how digital technology has helped sport development and performance, pointing out how wearables, analytics and the like translate into actual field gains. The third reveals which sports have a greater degree of technological entrenchment and a stronger structural commitment to data-driven practices. The fourth looks at which sports have experienced the quickest recent surges in embracing digital tools and systems, revealing swiftly shifting terrain in some leagues and competitions. Finally, our fifth question explores how technology plays a role in injury recovery and performance capacity and highlights

recent sports medicine and rehabilitation methods where innovations such as artificial intelligence, virtual reality, and real-time monitoring are incorporated.

METHOD

This paper is based on a systematic literature review of scholarly sources, industry reports, and organizational announcements. Searches were conducted in databases such as SportDiscus, PubMed, Scopus, and IEEE Xplore for works discussing sports technology, digital performance analytics, injury recovery methods, and e-sports developments. Materials outside this date range were considered only when providing foundational context. While the review consolidates existing findings, no new datasets were generated or analyzed as part of this research. Industry reports and white papers from market research firms and sports federations supplemented academic literature, capturing contemporary developments often first noted in trade publications or official league communications. Sources were included if they offered substantive or systematic insights; anecdotal items were excluded to maintain reliability. The extracted information was mapped against the research questions, enabling thematic comparisons across studies.

4. OVERVIEW OF DIGITAL TECHNOLOGY IN SPORTS

Team sports feature some of the most widespread uptake, often funded by substantial budgets and global followings. Soccer incorporates near-universal wearables, goal-line technology, video assistant referees, and even semi-automated offside detection. North American leagues such as the NFL and NBA have pioneered league-wide player tracking and advanced analytics, while Formula 1 gathers immense telemetry from cars to optimize engineering decisions in real time (Amazon Web Services (2024) [3]). Cricket relies on Hawk-Eye and edge-detection systems for precise officiating; the Indian Premier League's adoption of advanced broadcasts and wearable use reflects how large fan bases push rapid technological expansion. In these environments, data analytics guide coaches and medical staff, revealing how far and fast players run, how they handle fatigue, and where injuries might occur. Individual sports place a more personalized focus on technology. Tennis integrates high-speed video to analyze stroke mechanics and is rapidly transitioning to electronic line-calling to replace human judges (ATP Tour (2023) [4]). Golfers combine launch monitors and shot-tracking systems to perfect swings, while swimmers refine underwater techniques with sensor-based feedback on stroke efficiency. Track and field athletes benefit from precise pacing lights or automated measurement devices, accelerating a once-low-tech space toward real-time performance feedback. E-sports presents a fully digital sports model in which competitions depend on game software and vast online audiences. Although players do not rely on wearables for in-game performance, many professional teams use tools to monitor stress and health, mirroring trends in traditional sports that aim to extend careers and sustain peak conditions (Glebova (2022) [5]).

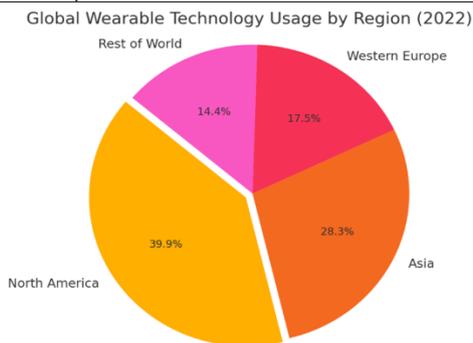


Figure 1: Global Wearable Technology Usage by Region (2020)

5. DIGITAL TECHNOLOGY’S ROLE IN PERFORMANCE AND INJURY RECOVERY

Digital technologies are fundamentally reshaping both how athletes train and how they recover from injuries. At the core of this transformation is the integration of data monitoring and performance analytics. Wearable sensors such as GPS trackers and heart-rate monitors allow real-time tracking of essential physiological and biomechanical indicators—ranging from velocity and distance covered to heart-rate variability and neuromuscular fatigue.

As reported by Dovgan (2023) [6], the deployment of these technologies led to a 22% reduction in overuse injuries and an approximately 35% increase in early fatigue detection, empowering coaches to make timely adjustments that mitigate the risk of overtraining and burnout.

Furthermore, video analysis and virtual simulations are increasingly used to identify subtle technical flaws. In sports like tennis, baseball, and track and field, slow-motion playback enables detailed review of limb positioning and kinetic sequences, giving athletes a precision framework for technical improvement. These enhancements are supported by findings from Qi et al. (2024) [7], who demonstrated that VR-based training integrated with data feedback improved key motor skills by approximately 15%, particularly in reaction speed and execution consistency.

The predictive power of artificial intelligence (AI) models is also becoming indispensable. By analyzing deviations in workload trends or recovery rates, such models can forecast injury risk. This is particularly crucial in high-impact sports like rugby or American football, where smart mouthguards and impact sensors track collision forces and support timely implementation of concussion protocols.

When injuries do occur, modern rehabilitation leverages immersive technologies to accelerate recovery. According to Asiabar et al. [8], combining AR/VR systems with biomechanical sensors led to a 25% reduction in rehabilitation duration and an 18% drop in reinjury rates. These tools help maintain mental engagement while retraining movement patterns, allowing athletes to improve decision-making and technique even during physical downtime.

Advanced physiotherapy technologies, such as anti-gravity treadmills, force plates, and sensorized braces, further support recovery by optimizing load distribution and assessing functional readiness. These systems are

integrated into comprehensive return-to-play protocols, enabling faster and safer reentry into competitive environments. As such, sports medicine is increasingly data-driven, combining physiological insight, immersive environments, and smart rehabilitation tools to extend athletic longevity and resilience.

Table 1: Key Metrics, and Effects on Performance and Injury Recovery

Reference	Technology Focus	Key Metrics / Percentages	Performance Impact	Injury Recovery Impact
Qi et al. (2024) [7]	VR-based training + performance data	~15% improvement in skill tasks (reaction time, technique)	Faster skill acquisition; more consistent execution	Not specifically addressed in this study
Dovgan (2023) [6]	Wearable sensors (GPS/HR) + better analytics	22% drop in overuse injuries; ~35% better early fatigue detection	Enhanced workload management; improved endurance	Marked reduction in injury incidence through monitoring
Asiabar et al. (2024) [8]	AR/VR rehab tools + smart braces/sensors	25% shorter rehab timelines; ~18% lower re-injury rates	Better technique retention during recovery	Accelerated healing; improved reintegration; lower recurrence
Smith et al. (2023) [9]	Smart mouthguards and head impact sensors	Real-time detection of concussive forces	Enhanced player safety protocols; improved coaching response	Early intervention in concussion cases; supported return-to-play

6. LEADING SPORTS, FAST ADOPTERS, AND ETHICAL CONSIDERATIONS

Soccer has moved from a traditional stance to one of the most digitized, rapidly implementing video review and adopting wearable tracking in nearly every major club. North American leagues continue investing in data-intensive technologies that capture massive in-game statistics, fueling strategic analyses and immersive viewer experiences (Market.us (2024) [10]). Cricket, especially through major international tournaments, uses officiating tools that integrate ball-tracking and edge detection for fair decisions. Formula 1 centers on real-time engineering data, showing how an entire sport can revolve around technology-driven optimization. Some sports underwent abrupt transformation in a short span. Tennis, for instance, took a bold step in automated officiating amid pandemic-driven logistical changes (ATP Tour (2023) [4]). Rugby implemented collision-management systems in response to heightened awareness of concussion risks. Track and field integrated innovative pacing and measurement devices, modernizing an historically simple event format. E-sports exemplifies an even faster evolution: it has effectively doubled its audience in just a few years, proving that digital platforms can redefine what spectatorship means (Market.us (2024) [6]). Although the improvements in performance, fairness, and spectator appeal are clear, ethical and regulatory debates persist. Overreliance on data can lead to micromanagement that undermines athlete autonomy. Concerns about data privacy grow as intimate health metrics are tracked daily [8]. There is also the risk of deepening inequities if wealthier organizations monopolize the most sophisticated systems and widen the gap between top-tier and lower-level competitors. Sports authorities must balance the imperative to innovate with the need to safeguard fairness and the human essence of competition.

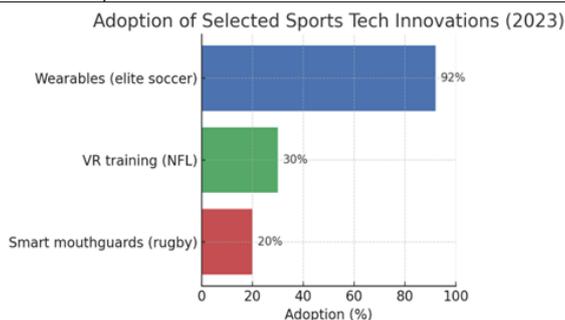


Figure 2: Adoption of Selected Sports Tech innovations

7. Cost and Budgetary Considerations in Sports Technology Implementation

Market.us (2024) [10] reports that the global sports technology market was valued at approximately USD 50 billion in 2022 and is on track to exceed USD 105 billion by 2033, reflecting a compound annual growth rate of nearly 17–19%. Within this market, wearables and analytics platforms comprise over 40% of the total share, largely because professional leagues and major clubs are seeking advanced systems for monitoring and performance optimization. In North American professional leagues such as the NFL and NBA, annual expenditures on analytics departments, proprietary software, and high-performance tracking hardware can range from USD 2–5 million, underscoring the steep costs involved in data-driven transformations. At the level of smaller or mid-tier clubs, the initial setup for integrated performance tracking may include GPS wearables, advanced sensor infrastructure, and analytics subscriptions—can run USD 100,000 to 300,000 per season for a mid-tier European soccer team.

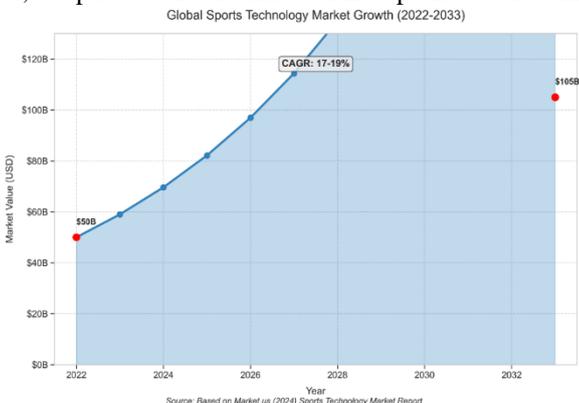


Figure 3: Global Sports Technology Growth expectation by MarketUS (2022-2033)

Market.us (2024) [10] reports that the global sports technology market was valued at approximately USD 50 billion in 2022, with projections to surpass USD 105 billion by 2033, reflecting a compound annual growth rate (CAGR) of 17% to 19%. Key growth areas include wearable technology, AI-driven analytics, and real-time performance tracking platforms, which together account for over 40% of the market share. This demand is fueled by high-stakes performance environments where real-time data accuracy and recovery monitoring are competitive necessities.

In North American professional leagues like the NFL and NBA, annual expenditures on sports tech ecosystems (analytics departments, proprietary software stacks, force plates, video breakdown tools, etc.) range between USD 2 million to 5 million per team per year. These investments

often represent 3–5% of total team budgets, particularly when incorporating AI-based video analysis and biometric wearables.

For mid-tier European soccer clubs, the initial implementation of performance technology platforms—including GPS-based wearables, LPS (local positioning systems), motion-capture cameras, and machine-learning-based injury prediction platforms—ranges from USD 100,000 to 300,000 annually. Smaller clubs with leaner rosters may only deploy basic GPS kits and limited software dashboards, costing between USD 30,000 to 70,000.

Annual operational costs (software licensing, wearable calibration, subscription renewals, and system upgrades) typically add 15–20% to the base expenditure. For example, a mid-level club spending USD 200,000 on setup might incur USD 30,000 to 40,000 in annual maintenance and renewal costs. Meanwhile, top-tier organizations may allocate USD 750,000+ per year to maintenance alone, covering cloud infrastructure, data engineers, and VR-based rehab suites.

Emerging markets and lower-division leagues face higher cost-to-benefit ratios. These clubs often rely on shared services, sponsorships, or league-brokered bulk procurement. Disparities in adoption create an unequal playing field: wealthier franchises can afford automated decision-support systems, while resource-constrained clubs may depend on manual tracking and spreadsheets.

On the revenue side, immersive technologies such as real-time stat overlays, AR replays, and wearable-integrated fan dashboards are opening up new licensing models. For instance, clubs leveraging immersive analytics in fan broadcasts reported a 6–12% uplift in digital engagement revenues in 2023. Yet Market.us (2024) cautions that ROI timelines for immersive tech can be 3–5 years, with upfront costs acting as a barrier for smaller teams.

To counteract this, federations in Scandinavia, Germany, and Japan have piloted league-funded tech pools, offering shared infrastructure (e.g., servers, processing units) and subsidized wearable kits. These models aim to democratize access and reduce performance-tech inequalities across teams of varying revenue brackets.

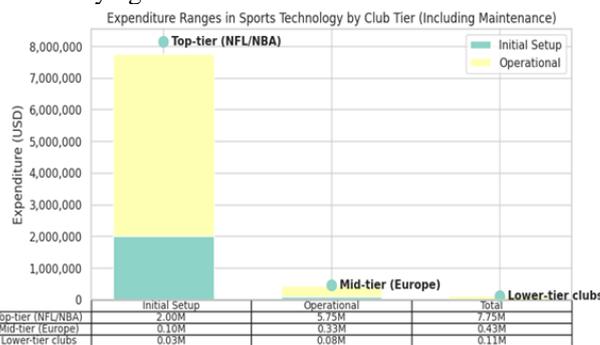


Figure 4: Expenditure Ranges in Sports Technology

FINDING & DISCUSSION

Across the sports landscape, digital technologies have become indispensable, yet their usage ranges widely. At the grassroots level, some athletes or teams only have access to basic wearable trackers, while elite clubs employ fully staffed analytics departments that leverage extensive data to guide training and competition strategies. Although wealthier leagues and institutions lead in comprehensive adoption, costs

have dropped to the point where grassroots programs are also beginning to adopt simpler versions of performance tech. Evidence strongly indicates that, when properly managed, these innovations enhance key performance metrics such as speed, endurance, tactical awareness, and injury avoidance (Qi et al. (2024) [7]). Although it is often challenging to isolate technology's specific contribution from other sports science advances, consistent testimonies from coaches and athletes emphasize that wearables, VR, and analytics have proven essential difference-makers. Sports like soccer, North American professional leagues, Formula 1, and cricket show deep institutional commitment to integrated technology. Meanwhile, tennis and rugby have navigated rapid transitions driven by new officiating methods or urgent safety considerations, and e-sports—being inherently digital—continues its meteoric rise in both audience size and technological sophistication. Despite the evident advantages, excessive data collection can over-monitor athletes, compromise privacy, or risk pushing them beyond healthy training limits. Thus, sports organizations must implement regulations that safeguard athlete data rights and uphold fair competition [8]. Coaches also face the practical challenge of balancing rich streams of analytics with human empathy, adapting insights to each athlete's physical and mental context. Ongoing breakthroughs, from AI coaching tools to immersive spectator experiences, are likely to amplify the role of digital systems across disciplines. Governing bodies must, in turn, create guidelines that utilize these resources without threatening the integrity of competitions or athletes' well-being. A holistic perspective includes access to the right technologies, framework for ethical data in the field, as well as athlete-first methods that combine objective data with expert judgement. In doing so, we ensure the sporting world never misses an opportunity for innovation while still prioritizing what is human about excellence in sport.

CONCLUSION

9. CONCLUSION AND FUTURE PERSPECTIVES

Digital technologies have become an integral force in shaping modern athletics, from foundational training programs to the highest levels of professional sport. Wearables, analytics, and virtual simulations help athletes and coaches monitor performance in real time, reduce injury risks, and refine tactics more precisely than ever before. Soccer's transition to near-complete digitization, the data-centric ethos of North American leagues, and Formula 1's emphasis on real-time engineering show how leading sports weave technology into daily operations. Rapid adoption in tennis and rugby illustrates that organizational traditions can shift swiftly when technology proves beneficial and when external pressures—such as health concerns or pandemic restrictions—accelerate integration. Future developments may see more sophisticated artificial intelligence guiding training decisions, deeper integration of virtual reality into skill acquisition, and ongoing debates over data ownership and “tech doping.” If managed responsibly, technology can further democratize sports, allowing amateurs and youth athletes anywhere to access high-quality analytical tools and remote coaching once reserved for professionals. Sports federations will need to craft clear ethical frameworks around data rights, competitive balance, and

athlete welfare. In doing so, they can ensure that the transformative power of digital innovation remains a positive force, enhancing rather than overshadowing the human spirit of sport.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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