The Use of Developing Technology in Sports

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Assoc. Prof. Dr. Işık BAYRAKTAR

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Foreword

It is seen that sports, as a part of social culture, is affected by developments and innovations throughout history and social process. From the increase or decrease in the popularity of sports according to socio-cultural changes, to the greater adoption of different sports practices in different geographies, all can be considered as a result of the dynamism of sports. Especially with the industrial revolution, developments in sports practices have progressed parallelly. The development of materials in several sports events has also supported the improvement of performance. While objective outcome evaluations have become more sensitive under those conditions, subjective outcome evaluations have become as rational as possible due to the developing technology. This condition has strengthened the factor of "fairness", which is one of the main foundations of sports.

Nowadays, we are trying to get used to the fast intervention of the development of technology, digitalization, and the use of artificial intelligence in our lives and even in our clothes with wearable technology. Athletes, coaches, managers and other supporting variables of the athlete, are trying to use the newest generation of sports technology as much as possible. It will be very important to closely follow the developments of digitalization and to be able to use functional products in health and performance development.

The purpose of this book is to share current developments and trends regarding the use of developing technology in sports, to examine the current state of artificial intelligence applications in sports, and to give examples of the use of technology in different team and individual sport events. Further the book aimed to provide information about technological developments in outdoor recreational activities as well as in performance sports.

I would like to express my gratitude to all my colleagues who contributed to this book with the title "The use of developing technology in sports" by writing chapters.

I wish that this book will be beneficial to those who do research on the areas of developing technology in sports and to those who are interested,

Editor
Assoc. Prof. Dr. Işık BAYRAKTAR (PhD)

October, 2023
Alanya, Turkiye

Contents

Chapter 1

Revolutionizing Sport - How Technology is Changing the Sports Industry?

Pelin Avcı[1]

Akan Bayrakdar[2]

Abstract

This review aims to assess the impact of technology on the sports industry. Technology has played an increasingly important role in the sports industry over the last decade, modernizing the on-field experience for players, teams and leagues. For example, developments such as Video Assistant Referee (VAR) technology have revolutionized the way football games are decided and played, and game footage, telematics and heat maps have led to major advances in player performance management. However, these technology-led advances have largely remained confined to the playing field and the experience of sports fans has improved little in recent years. As technology continues to evolve rapidly, sports clubs now have a unique opportunity to reach their fans faster and easier than ever before, expanding their global reach and appeal. Overall, it is clear that wherever technology and sports intersect in the future, if technology and data are used in the right way, it will lead to great improvements for sports clubs, leagues, organizations, and most importantly, fans.

Introduction

Sport is a unique industry in that it is arguably the least predictable business in the world (Smith & Westerbeek, 2007). It is almost impossible to predict which team or athlete will win, how athletes will perform, which athletes will be subject to transfer or season-ending injury (Rea & Lavallee, 2015). These factors influence the demands of fans. This means that many sports teams may struggle to keep up with changing fan needs (Collins et

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al., 2016). However, as technology changes, clubs are now able to keep up with new trends and produce multiple pieces of fan equipment at the same time. This enables teams to meet fan demand and capitalize on emerging opportunities (Goodwin, 2004). For example, thanks to the work of top technology teams around the world, Fanatics was able to meet the huge increase in demand caused by the transfers of Lionel Messi and Cristiano Ronaldo to Paris St Germain (PSG) and Manchester United respectively in 2021.

Advances in technology attract the attention of the sports industry just as they attract the attention of other industries (Brannagan et al., 2022). Sport has always been at the forefront of technological adoption (Catalin et al., 2023). The global sports technology market is expected to reach a value of USD 40 billion by 2026. It is clear to see how technology is revolutionizing the way we play and experience sports. From advanced analytics and data visualization to assessment tools and streaming services, technology has changed the way we interact with and understand sport (Williamson, 2016).

One of the most significant changes technologies has brought to sport is the use of advanced analytics and data visualization (Watson, 2014). Teams and organizations can now collect and analyze massive amounts of data on everything from athlete performance to team strategy (Rein & Memmert, 2016). We don't need to be a professional athlete to access sports technology. Companies such as Whoop, which has received more than $400 million in total funding, offer wearables to track athletes' daily sleep, rest, and effort every hour of every day.

The adoption of technology is not limited to improving athletes' performance. Technology has changed the way fans interact and enjoy their favorite sport (Kassing & Sanderson, 2010). Esports is one arena that has pioneered the use of technology to connect with fans. Augmented Reality has been heavily featured in League of Legends or Counterstrike championship matches, with fans experiencing immersive action (Cranmer et al., 2021). One of the sports synonymous with the adoption of technology is F1. F1 cars undergo repeated tests every year to reduce friction and increase speed (Jenkins & Floyd, 2001). The cars have also become increasingly lighter while improving the efficiency of the engine. The current V6 F1 engine produces 26% more power than the 2013 V8 engines (Piancastelli et al. 2018). The cars have the advantage of utilizing the latest advances in fluid mechanics. F1 cars are built to be aerodynamically balanced and force the cars as low to the tarmac as possible. F1 has embraced technology in every aspect of the sport, from logistics to video production (Codling, 2017).

How is technology changing sport?

Thanks to technological advances, athletes can now participate in sports that are both safer and more competitive. You can now participate in Ice Hockey, Soccer, Basketball, and many other sports with confidence knowing that technology is here to help you. So, whether you work in the sports industry or are a die-hard fan, your experience is far ahead of what it was years ago thanks to technological advancements (Billings & Ruihley, 2013).

Every aspect of our existence is slowly but steadily changing due to technological advancements (Ahad et al., 2020). From the way we travel to how we take care of our health and how we have fun, technology affects our behavior and experiences in a variety of ways. People can now access information faster, communicate more directly and efficiently, and develop ideas as the world changes dramatically. From healthcare to government, education, business and sport, technology affects every aspect of life and every sector (Verma & Gustafsson, 2020). Although often not obvious, technology has had a significant impact on sport. The industry has seen an increase in interest and revenue as many organizations are now simpler and faster (Patel et al., 2020).

Technology has had a significant impact on sport in terms of improving athlete performance over time (Adesida et al., 2019). The art of keeping track of time is becoming increasingly complex. Technology allows runners, cyclists, swimmers, cyclists, and other athletes to compare their results to field norms, allowing athletes to make predictions on how to improve their performance (Neptune et al., 2009). Advanced simulations are now accessible for almost every discipline, making training and skills development much easier than before. For professionals and beginners alike, everything from a Formula 1 simulator to a stationary bike that simulates open road conditions (excluding weather) is accessible (Davenne et al., 2012).

Hawkeye, a computer system that displays the trajectory of a cricket ball, was first used in cricket in 2001. Hawkeye produces a variety of statistical analyses, including ball speed, wicket-taking, and the trajectory of the ball after bounce. In tennis, Hawkeye is now used to determine whether a shot is in or out. In addition, Hawkeye's analysis of sports performance has significantly increased audience understanding and engagement (Singh & Dureja, 2012).

Thanks to technological advances, sport is considered more inclusive than ever before. Whereas before viewers could only watch the match on a few networks, today there are many possibilities. There are also live broadcasts

and replays. When we missed a big match or event, it meant having to wait until the next day to see the results in the newspaper or hear about it from friends. Media outlets covering sporting events now use technology to deliver information faster than ever before (Otto et al., 2011). News and updates are sent to smartphones as soon as they are available. Moreover, social media offers opportunities that were previously unimaginable.

How can technology bring athletes and teams to a global audience?

Emerging technology has revolutionized fan access to clubs and athletes, opening up local teams and athletes to global fan bases. Today, fans of an athlete or club can be found in every corner of the world. As technology continues to connect athletes with new fans, athletes and clubs need to take into account different fan preferences and cultural norms. For example, what appeals to a fan in India may not be what appeals to a US-based fan, which means that clubs need to carefully consider their messaging and offerings for each market. Technology gives teams access to advanced digital analytics that allow them to study and predict fan attitudes and tastes. This allows clubs to tailor their messaging and product offerings to different fan bases around the world. At the same time, fans feel that their preferred product is catered for by the teams. This can also be achieved by working with partners who understand the needs of international sports organizations and their fans (Mastromartino & Zhang, 2020).

What can we see in the future?

There will continue to be untapped potential for technology to enrich the sports fan experience in the coming years. In terms of what this might look like, the possibilities are almost endless. There are a variety of ways in which sports teams can blend physical and digital channels to enhance the fan experience in new and exciting ways. For example, there is a good chance that in the future we will see match-going fans having regular access to exclusive in-game promotions and deals or being able to order their favorite player's jersey by scanning the QR code on their seat for a special discount (Sturm, 2020).

Advantages and Disadvantages of Using Technology in Sports

Technology brings benefits as well as disadvantages to sport. Sometimes technology needs to be integrated and improved to be fully effective. Despite these integrations and improvements, problems arise over time (Bressanelli et al., 2019).

Table 1. Advantages and Disadvantages of the Use of Technology in Sport for Athletes

Advantages	Disadvantages
Better performance- marginal gains make a difference	Violates confidentiality
Better medical care results in fewer injuries or faster recovery from injury	Blurs the lines between personal and professional time
Feedback from coaches is more focused, objective, and helpful	Availability and cost - playing sports and success exclusive to wealthy people and countries
Enhanced kit is more comfortable, more efficient, and safer	Encourages athletes and coaches to cheat or engage in unfair practices
Part of a team, not isolated	Focuses on winning, not athletic effort

Table 2. Advantages and Disadvantages of the Use of Technology in Sport for Officials

Advantages	Disadvantages
Supports a team approach, so there is less pressure on individuals	Slows down the game
Information can be easily and quickly shared and stored over time	Not available at all competition levels
Decisions and scoring are more reliable and accurate	Don't trust people's judgment anymore
Trust and confidence in authorities is growing	undermines respect for the knowledge and expertise of officials
	It undermines honesty, integrity, and the spirit of fair play

Table 3. Advantages and Disadvantages of the Use of Technology in Sports for Spectators

Advantages	Disadvantages
More interested in sports	Distracts from the real game
More information about rules, players, etc.	Reduces atmosphere at live events
Have a direct connection with athletes	Reduces interest in grassroots activities not supported by technology
	Increases audience/broadcaster costs
	Enables trolls to attack individual athletes

Table 4. Advantages and Disadvantages of the Use of Technology for Sport in Sport in General

Advantages	Disadvantages
Increases participation	Reduces the intensity of physical activity
Promotes new and alternative opportunities	Reduces emotional well-being from escaping digital pressures/routines
Supports fewer rich sports to promote themselves	Increases cost to sport and participants
Provides more coverage and revenue	Sponsors more interested in technology than sports or athletes
Attraction adds	
Improves safety	

Different Types of Technology in Sports Today

Accessibility: The total number of athletes competing in the 2020 Paralympic Games in Tokyo was 4403. The integration of technology with prosthetics has given countless athletes a second chance at life. The application of technology in sports allows athletes to compete in international competitions once again. The global prosthetics market is expected to reach a market worth US$ 8.6 billion by 2028. Organizations such as Ossur are leading the market in research and development to enable athletes to realize their dreams. These companies are striving to reduce the weight of prostheses and improve athletes' performance (Yashio et al., 2021).

Referees and Technology: Referees must consider many factors before making their decisions as they influence the outcome of a match and the entire tournament. The introduction of the video assistant referee (VAR) has made their job easier. VAR consists of a series of camera systems placed around the pitch to provide real-time feedback to the referee. The use of VAR in football has helped improve the accuracy of match decisions from 82% to 94% in 1 year. During the 2018 World Cup, the application of VAR in matches increased the correct referee decision from 95% to 99.32%. In addition, hawk-eye technology (DRS) is used in some sports (Volleyball, Tennis, Cricket, etc.). It is a technological system with the same logic as the VAR system. With DRS, players from both teams can challenge the decision made by the referee and ask for a review from the third referee (Zglinski, 2022).

Virtual Reality Technology (VR) in Sport: The COVID-19-induced curfew has forced organizations and athletes to think and implement out-

of-the-box training routines. One such new technology is Virtual Reality (VR). VR technology simulates a 3D representation of the real world where operators can add immersive details such as other players and even entire stadiums filled with the roar of fans. This sector is expected to be worth US$56.7 billion by 2026. VR is being used effectively in contact sports such as American football and Rugby. Due to the nature of these sports, the risk of developing chronic brain diseases increases as head injuries are repeated. One way to reduce this risk factor is to use VR during training sessions. VR allows athletes to understand strategies by simulating real-life field training. During the 2018 Winter Olympics, the US ski team was unable to train on the slopes of Pyeongchang. They trained and trained in VR on a digitally recreated terrain of the course. The US team silenced critics of the training method and won 1 gold, 2 silver and 1 bronze medal in various events. This result provided conclusive evidence of the validity of using VR to train athletes and improve their performance (Buhalis et al., 2023).

Fitness and Nutrition: 45% of all households in India have wearable devices. The sensors in these devices track everything from your blood pressure to your body temperature and heart rate (Wan et al., 2018). The sensors in wearables measure data and process and generate data in real time. The global wearable technology market is expected to reach US$62 billion by 2025. Sports teams around the world are integrating this technology into existing training programs to improve team performance and reduce athlete injuries. Wearables help athletes better understand fatigue and reduce the likelihood of serious injury. Teams using wearable technology saw an 88% reduction in soft tissue damage compared to the previous year. Nutrition is an integral part of fitness. Sports professionals push their bodies to absolute limits and have higher nutritional demands than normal people (Brito et al., 2012). Usually, elite athletes consume around 2000-6000 calories every day. Athletes also need supplements that help them meet their nutritional requirements. Sports teams use devices that catalog various energy expenditure parameters, such as body Bugg, to track and meet athletes' daily calorie requirements. These devices use data generated from various sensors to calculate the total calories consumed and suggest improvements to the athlete's diet. These devices leverage the computing power of machine learning algorithms to gain actionable insights into the athlete's dietary health. Devices such as Body Bugg communicate with web applications such as MyFitnessPal, qualori king, eDiet to create a diet plan that targets and refines the calorie and supplement requirements of individual athletes. These supplements include protein and vitamin supplements and minerals

such as Magnesium, Iron and Sodium. Supplements alone account for 50% of the US$40 billion global sports nutrition market (Telessy, 2019).

Stat-Tracking and Analytics: Keeping track of player statistics is a challenging task when done manually. However, technology has made it possible to keep track of stats that even humans can't measure. An example of this is SportVU, which is a system that tracks everything that's happening in the basketball court, such as where the ball is going and the movement of the players (Acuna, 2020). Technology has granted us access to an ocean of data which fans, players, and most especially coaching staff, can benefit from. With analytics data, teams can now make more refined adjustments and coaching staff no longer have to rely on pure intuition and skill when devising a game plan. Sports teams can now utilize math in improving their play, exploiting their opponents, and getting ahead of the competition (Correia et al., 2019).

Injury Prevention and Rehabilitation: The likelihood of getting injured is one of the hard truths of every sport. Athletes risk their bodies and their well-being not just for the entertainment of sports fans, but also for the glory of winning, and we can't blame them. Playing at the highest levels requires exerting the most effort, and an injury is a possible consequence of this intense commitment to competition. Thankfully, technology has made it possible to avoid injuries across various sports. For example, there are high-tech mouth guards which use sensors and determine whether impact is serious or negligible so that collisions which may seem normal but are actually threatening can be detected and acted upon. Furthermore, technology has made it possible to rehabilitate injuries better, such as through the use of digital modeling, which allows for the finding of a source of injuries to body parts such as the elbow and the arm, so that proper treatment may be effected as soon as possible (Bachynski & Goldberg, 2014).

Ticket Purchases: Back then, watching your favorite team live can become an ordeal before you even get in the stadium. Ticket lines are always a hassle and it's not even guaranteed that you get the seat that you want. Nowadays, tickets can be purchased online either directly from the league or the team you follow or from ticket-selling websites. With this technology, you won't have to worry about waiting in line for nothing and you can even pick which seat you want (Guschwan, 2016).

High Definition: Not everyone can afford tickets to live games, but it doesn't mean that they shouldn't enjoy watching their favorite sport. Today, everything is in high definition, and sitting at home watching the game on

your TV, your computer, or your phone is almost like watching the game in real life with how clear the action (Heller & Bar-Zeev, 2021).

Sports Video Games: It's not uncommon for fans to wonder what it feels like to play at such a high level as their favorite players since professional athletes can sometimes seem to have superhuman abilities. Although there isn't any technology yet that will actually put fans in the players' shoes, fans can at least simulate their favorite sport and play as their favorite team in video games, allowing for a unique and immersive sports experience. Video games can even serve as a gateway for players to become fans of a sport they didn't use to follow (Rehman et al., 2023). Someone who's clueless about basketball can play a game of NBA 2K with a friend and realize how thrilling the game can be, and before you know it, he's filling his closet with his hometown team's jerseys.

Conclusion

As technology and our approach to sport will always be connected, more innovative and lighter shoes, jerseys, balls, and bats will emerge. But let's not forget that sport is still about celebrating human achievement and victory over self and others. No matter how sophisticated our technology becomes, it is human beings who will continue to lift, run, and jump, whether or not our bodies are wrapped in high-tech products.

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Chapter 2

Artificial Intelligence & Sports

Murat Meriçelli[1]

Mürsel Ozan İncetaş[2]

Abstract

Artificial Intelligence has gained tremendous momentum with factors such as increased computational capacity, big data analysis, and the development of deep learning algorithms. Artificial intelligence is redefining the rules of the game and the performance of athletes, entering the world of sports, which originates in human history. The use of artificial intelligence in sports can be summarized under the following eight key areas: Training Programs, Score Predictions and Betting, Health Applications, Tactical Strategy and Transfers Determination, Referee Decision Support Systems, Artificial Intelligence Playing Sports and Esports-Sports Journalism, Wearable Technology and Sensor Data. This close collaboration is reshaping the future of sport by fundamentally altering the experience of both athletes and fans. Combined with technological innovations, sports have the potential to provide a more efficient, effective, and entertaining experience. Sports and artificial intelligence can combine to deliver unforgettable moments for both athletes and spectators, but an approach that balances this evolution is required. Therefore, this close cooperation between sports and artificial intelligence should be managed with a perspective that attaches importance to ethical values and human factors.

INTRODUCTION

It is possible to talk about the concept of digitalization and the impact of computers on human beings' lives on many different issues in daily life. Individuals' interaction with information technologies started with the emergence of personal computers, and large masses have been digitalized

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with several developments, such as the development of the Internet-based Web and the emergence of mobile applications. Artificial intelligence (AI), which was the subject of science fiction movies until the recent past, has become an essential field of study in computer science, and today it is seen that departments named "Artificial Intelligence Engineering" have been established in informatics faculties (YÖK, 2023). So what is the AI? Although people generally think of intelligent robots taking over the world, is it so?

AI refers to machines and computational methods endowed with the ability to perceive, store information, and make decisions aligned with predefined objectives (Chris et al., 2022). AI has surged forward, driven by factors like augmented computational capacity, big data analysis capabilities, and the continuous development of deep learning algorithms. AI aims to create systems with human-like abilities to solve complex problems and make decisions. Recently, AI applications have significantly succeeded in many areas, such as image recognition, natural language processing, game strategy development, and autonomous driving.

New technologies and research applications in the AI field have created a significant revolution in the world of sports in recent years. Sport has always attracted great attention as an activity based on maximizing people's physical abilities and performing in a competitive environment. However, the introduction of AI into the world of sports is redefining the rules of the game and the performance of athletes (Chmait & Westerbeek, 2021).

The convergence of AI and sports science confers substantial advantages in optimizing athlete performance, mitigating injury risks, and refining game strategies. For instance, AI can conduct biomechanical analyses by closely monitoring athletes' movements, offering valuable insights to help athletes enhance their techniques (Ding, 2019). Furthermore, big data analysis supports tactical development processes while making training programs more personalized. Rapid technological advances in computer science and the evolution of sports science have led to a unique coming together of these two distinct fields. By combining these two disciplines, AI has significantly impacted several areas, such as sports analysis, performance optimization, and sports broadcasting. This chapter embarks on the development of AI in computer science and sports sciences and discusses what innovations these two fields bring forward.

METHOD

This study has been prepared as a literature review.

SPORTS ACTIVITIES

The origins of sports go back to human history. People survived by using their physical abilities during the hunting and gathering periods. Over time, these activities have evolved into events carried out for ritual, entertainment, and competition purposes. Crucial insights into the origins of sports can be gleaned from the historical records of civilizations such as Sumer, Egypt, Ancient China, and Ancient Greece. Events like the Olympic Games in Ancient Greece stand as a testament to the transformation of sports into endeavors that acquired a social and cultural significance (Akıncı, 2022) (Tekin & Tekin, 2014). The foundations of modern sports were laid in the 19th century. Industrialization, urbanization, and the development of communication technologies have enabled sports to gain a more organized and institutional structure. Modern sports have become an area where rules are determined, and national/international organizations are organized (Atasoy & Kuter, 2005)(Ekmekçi et al., 2013). The development stages of sports can be summarized as follows (Akıncı, 2022)(Tekin & Tekin, 2014) (Ekmekçi et al., 2013)(Atasoy & Kuter, 2005):

- Practicality and Survival: Early humans relied on skills like hunting, running, and jumping for survival.
- Rituals and Worship: Sports were part of ritual and religious activities. In ancient times, games dedicated to the gods were organized in civilizations such as Greece and Rome.
- Competition and Entertainment: Sports evolved into events organized for competition and entertainment, with the Ancient Olympic Games serving as the oldest example of this transition.
- Institutionalization: The foundations of modern sports were laid in the 19th century. Rules and organizations were established. Sports such as football, tennis, and cricket have become popular.
- Moving to the International Arena: Thanks to the development of communication technologies, sports events began to spread internationally. International tournaments and events were organized.

Sports play many essential roles in human life and contribute to various aspects. The importance of sports in human life can be summarized as follows:

- Health and Physical Well-Being: Sports are an integral part of physical activity and form the basis of a healthy lifestyle. It promotes cardiovascular health, muscle strength, and weight management (İmamoğlu, 1992).
- Mental Health: Exercise can alleviate stress, mitigate depression, and bolster mental well-being by increasing endorphin production.
- Entertainment and Stress Reduction: Engaging in and watching sports allows people to have fun and reduce stress (Çoruh, 2019).
- Social Bonds and Social Integration: Team sports or group activities strengthen social bonds, enhance teamwork, and contribute to social integration (Duman, 2020).
- Discipline and Self-Control: Sports require regular training and participation, encouraging discipline and self-control.
- Character Development: Participation in sports fosters character traits such as leadership, teamwork, and competitiveness.
- Cultural and National Identity: Some sporting events express national or cultural identity. For example, the Olympic Games create a unifying effect at the international level (Şahin et al., 2010).

As sports development continues in parallel with social changes, its importance in human life has become more diverse and deepened. Its role in health, social bonding, mental well-being, character development, and cultural context indicates that sport is indispensable to human life. Professional and amateur sports or participation-based physical activities have an important place in the daily lives of human beings. At this point, it is impossible for sports, which represents a vast industry, not to be affected by AI applications. This interaction is seen in different research and practical applications.

SPORTS AND ARTIFICIAL INTELLIGENCE RELATIONSHIP

The sports ecosystem has four essential components: Athlete, judge, coach, and fans. These components help make the complex sports ecosystem easy to handle. The use of AI technologies in sports can be discussed through four main components as follows (Laukyte, 2020):

1. Enhancing athletes
2. Advising the Coaches

3. Supporting judges
4. Involving the fans

With AI, training programs can be created to improve athletes, and injury prevention and health monitoring can be carried out. Steps to determine tactics, strategies, and transfers to support coaches are possible with player monitoring based on sensor data. Many sports teams use artificial intelligence to analyze and improve player performance. For example, "SportVU" cameras in basketball track players' movements and collect data. Then, the data are analyzed to understand better player movements and team performance (Westney, 2015). Video referee systems support referee decisions using artificial intelligence in sports like football. These systems help make more accurate decisions in disputed positions by analyzing match footage. Some sporting events use AI-based applications to provide more personalized experiences for spectators. For example, mobile applications can offer spectators the best seat recommendations (Microsoft, 2017) or facilitate food and beverage orders. Wearable technologies and AI monitor athletes' training data and physical health. These data help athletes perform better. In general, the use of AI in sports can be grouped into the following eight items:

1. Training Programs
2. Predictions and Betting
3. Health Applications
4. Deciding Tactical Strategy and Transfers
5. Referee Decision Support Systems
6. AI Playing Sports and Esports
7. Sports Journalism and Fans
8. Wearable Technology and Sensor Data

Training Programs

Using AI technology in sports training can potentially improve traditional training methods. AI can perform precise data analysis, provide personalized recommendations, and simulate realistic training scenarios. In this way, it can help athletes train more effectively and increase their athletic performance. Additionally, integrating AI into sports training can offer new and innovative training methods for athletes (Wei et al., 2021). AI is used to examine the performance of athletes on the field, create training programs, and increase

training efficiency. This technology has provided data collection, analysis, and prediction capabilities to evaluate athletes' performance and optimize training programs (Özsoy et al., 2023). Current training tracking is possible with drones (Sever Hilmi, 2019), and detailed analysis of past competition data and performance tracking of athletes is possible with sports analytics companies such as OPTA3 and Stats4 (Beal et al., 2019). In addition, applications such as Athletica, FitnessAI, Freeletics, Cure.fit, Fitbod, and Vi Trainer can serve as fitness coaches or personal coaches and create training programs for individual athletes.

Predictions and Betting

Predicting the behavior of large and complex systems has been the focus of research in many branches of science. Different examples can be given, such as the forecast of stock markets and exchange rates in the near future or the weather forecast for the next month. Predicting the consequences of unrealized events based on historical data is of great importance for many people and organizations (Karaoğlu, 2015). As the sports betting industry and technology have experienced significant growth, it is now even more critical to predict the outcome of a sporting event using a technology-driven approach. People are subject to certain limitations when processing large amounts of information. However, artificial intelligence techniques can overcome this problem.

Additionally, sports have a large data pool to consider (Fialho et al., 2019). There are different applications regarding this in the literature. For example, in estimating the number of Athletes (Wrestlers), the number of athletes for the next two years was estimated using Artificial Neural Networks with the data of the past ten years (Dalkılıç et al., 2017). Bayesian Networks were used to predict football match results with artificial intelligence (Min et al., 2008) in the study conducted for 16 football leagues; the most successful predictions were obtained with the Decision Table technique (Karaoğlu, 2015). Data such as Points, Opposing Team Points, General Performance, Home Performance, Away Performance, Performance in the Previous Match, Performance in the Previous *n* Matches, Team Ranking, Points in the Previous Match, Points in the Previous *n* Matches, Position, Player Status were used in score prediction with the help of the MLP technique (McCabe & Trevathan, 2008). The examples here can be multiplied; However, summary data such as Table 1 and Figure 1 will be helpful to perceive the distribution tendencies of the algorithms in this scope. The frequencies of the algorithms used in score predictions were found as follows for 31 different studies (Bunker & Susnjak, 2022).

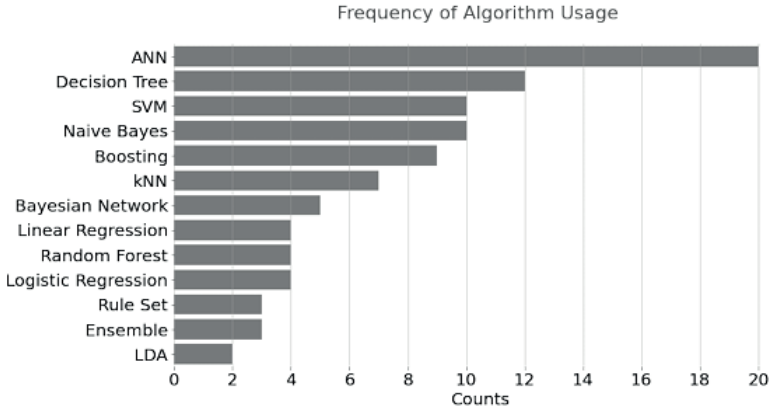

Figure 1 Histogram of AI algorithms used in sports studies. Source:(Bunker & Susnjak, 2022)

Table 1 presents a summary of the findings regarding the use of machine learning (ML) algorithms from AI techniques and their prediction success rates in competitions in different types of sports.

Table 1 Machine Learning Algorithms Used in Match Prediction. Kaynak: (Beal et al., 2019)

ML Method	Accuracy of Result	Sport
Neural Networks	68.8% (Hucaljuk & Rakipovic, 2011)	Football
	72.2% (Shi et al., 2013)	Basketball
	67.5% (McCabe & Tevathan, 2008)	Rugby
Decision Trees	41.72% (Joseph et al. ,2006)	Football
	69.16% (Shi et al. 2013)	Basketball
	58% (McCabe & Tevathan, 2008)	American Football
Clustering Methods	50.58% (Joseph et al., 2006)	Football
SVM(Support Vector Machines)	75% (Jayantha et al.,2018)	Cricket
	54.5% (Baboota & Kaur,2018)	Football
Random Forest	56.5% (Baboota & Kaur,2018)	Football
	62.2% (Shi et al., 2013	Basketball
Gradient Boosting	56.7% (Baboota & Kaur,2018)	Football
	68.8% (Hucaljuk & Rakipovic, 2011)	Football

It will be useful to consider the following principles in studies on match score prediction (Bunker & Susnjak, 2022):

- Low-scoring sports may have higher unpredictability.
- Lower competitiveness means higher predictability.
- Sports with more probable outcomes are less predictable.
- Better features and richer data sets tend to increase predictability.
- Different scoring systems have effects on predictability.
- Predictability is ultimately multifactorial.

Health Applications

Sports medicine has emerged as an essential medical branch that undertakes the tasks of protecting, repairing, developing, and rebuilding the human motor system. Sports medicine has a broad perspective and aims not only to heal after trauma but also to improve the performance of athletes and prevent injuries (Cheng et al., 2023). Injuries to professional players can have a significant impact on their careers. These injuries not only affect the player's career but can also negatively affect the team's performance. A player unable to play due to injury may reduce the team's chances of winning, which may result in the team's drop in the rankings. Additionally, when a player is injured, the team may face additional financial burdens, such as hiring a temporary player to replace him or paying the salary of a benched player. Therefore, athlete injuries have a significant impact on both individual careers and the performance of teams (Beal et al., 2019). For these reasons, the provision of AI in sports health practices is precious. In this context, GPT-4 AI applications within the scope of sports medicine can be considered as follows (Cheng et al., 2023):

- Diagnostic Imaging
- Exercise Program and Medical Observation
- Sports Nutrition
- Medical Supervision
- Medical science research

Deciding Tactical/Strategy Transfers

Sports teams use AI to analyze opposing teams' playing strategies and player behavior. Specific criteria may be needed when using AI in team sports. For instance, questions such as what is the role of the tactic or what

affects the decision need to be answered. Games such as tennis and volleyball involve less contact and players, while sports such as football and American football entail more contact. This complexity results in variations in tactical formations and strategies for each team sport and necessitates differences in the AI systems guiding them (Mozgovoy et al., 2021). Data such as past competition, training, health, and sensor data are analyzed for this. These analyses are used to make better decisions during the game. In team sports, AI can analyze the team's performance and make tactical recommendations (Pavitt et al., 2021). For example, AI can analyze football teams' matches and offer suggestions to optimize offensive strategies, defensive formations, or player positions. Clubs send scouts to evaluate various athletes, collecting extensive data encompassing variables like playing style, strengths, weaknesses, and work ethic. AI aids clubs in making transfer decisions by effectively processing this vast amount of data (Rathi et al., 2020).

Referee decision support systems

The use of AI in referee decision support systems emerged, intending to improve the accuracy of decisions in sports. The applications of these support systems in various sports have increased in recent years. The Instant Replay application is utilized in various sports, including baseball, basketball, cricket, fencing, football, American football, ice hockey, hockey, motorsports, rodeo, and rugby.

In football, the Video Assistant Referee (VAR) application is employed in situations such as goal/no-goal, penalty/no-penalty, direct red card decisions, and the correct player identification when issuing red or yellow cards. Following its introduction in the 2018 World Cup, VAR has been adopted in numerous competitions across different leagues worldwide (FIFA, 2022). The percentage of correct decisions, 93% before VAR, increased to 98.80% after VAR. There is also ongoing discussion about the more extensive use of applications during the trial phase, including semi-automatic/automatic offside determination and the automatic determination of whether the ball has crossed the goal line (Rathi et al., 2020). In sports like tennis, cricket, and volleyball, where ball tracking is crucial, the Hawk's Eye system is employed. This technology, developed in 2000, led to rule changes, such as introducing the right to challenge decisions in tennis and volleyball. Two alternative technologies, Cyclops and FoxTenn, are also essential in these sports.

Additionally, cricket uses the Snickometer for audio and video tracks; tennis employs the Electronic Line Judge for line tracking, and time-based

athletics sports rely on the Fully Automatic Timing (FAT) system (Kapil, 2018). Debates continue about the potential for AI to completely replace the human factor in officiating, with some suggesting a complete transition. In contrast, others believe humans will always have a role at the assistant level (Rathi et al., 2020).

AI Playing Sports and E-Sports

It is indeed fascinating that AI has a direct involvement in sports. On May 11, 1997, IBM's Deep Blue computer achieved a momentous victory over the world chess champion after a six-game battle, marking a pivotal turning point (IBM, 2011). One of the central questions in Human-Computer interaction is whether machines can exhibit behavior akin to that of humans. The "Frías-Triviño" test, akin to an adaptation of the renowned Turing Test for sports, comprises four inquiries or stages (Frias & Triviño, 2017):

1. Can robots understand the rules and traditions of the game?

2. Can robots develop physical abilities?

3. Can robots embody the emotional attitude of striving for physical perfection?

4. Can sports with robotic participants have institutional stability?

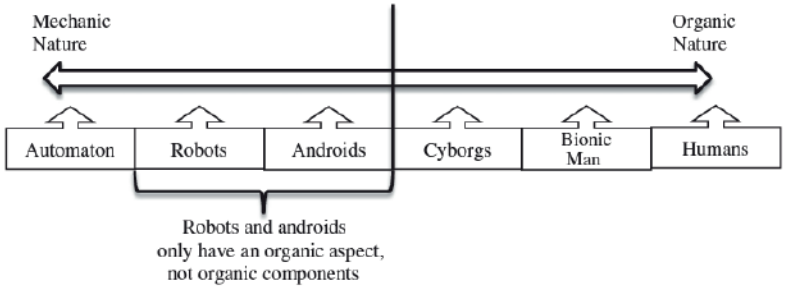

Figure 2 From automatons to humans. Different types of beings depend on the combination of organic and mechanical nature. Source.:(Frias & Triviño, 2017)

The transition from humans to automatons is depicted in Figure 2. Can human-like robots really play sports? In popular culture, robots are playing football like humans in the cartoon GGO Football (GGOFootball, 2010). The concept of creating robots with human-like behavior has perpetually intrigued humans.

The International E-Sports Federation defines *e-sports* as "a competitive sport in which players use their physical and mental abilities to compete in various games in a virtual, electronic environment" (IESF, 2021). Nowadays, E-sports is an industry, and professional YouTubers are in this field. In e-sports, game types and applications such as MOBA, FPS, RTS, Battle Royale, Sports, MMORG, and Fighter can be mentioned (Çağlayan & Uygur, 2022). The example given here is AI's success in a game involving complex thinking skills. The success rates of the new AIs in the 2012 HD Edition and the 2017 versions of the Age of Empires II game, which was introduced by Microsoft Games in 1999, are attractive in winning this game that requires complex strategy and planning (Fandom, 2017).

Sports Journalism and Funs

AI technology has ushered in an era where robots assume control of sports media broadcasts. This technological advancement streamlines the interpretation of games and the precise dissemination of sports content through the media, obviating the necessity to dispatch camera crews to various media outlets. Consequently, sports content is directed with greater accuracy and efficiency, thanks to the control of automated media broadcasts (Nadikattu, 2020). The availability of data streams, the burgeoning demand for news on mobile devices, and the continuous advancement of algorithms contribute to the increasing prevalence of automated journalism. Against the specific background of sports journalism's content, means of production, and consumption, the question the article answers is that the imminent rollout of auto-generated content may only herald another evolutionary stage in sports journalism (Galily, 2018). Spectators hold a pivotal role within the sports industry, serving as a vital source of revenue. This scenario underscores the application of AI solutions to serve the audience directly. These solutions may encompass elements designed to enhance interactive enjoyment, such as real-time sharing of scores and statistical data with fans, automated rewind and replay features, and predictions regarding ticket sales, match outcomes, and tournament victors.

Wearable Technology and Sensor Data

Wearable technologies are portable devices that can be worn as accessories or integrated into clothing, including mobile devices. These devices have the capability to capture various sensor data. Through wearable technology, data such as blood pressure, heart rate, body temperature, electrocardiogram (ECG), electroencephalogram (EEG), sweat analysis, and measurements related to displacement, speed, and acceleration can be collected and

processed using AI. This data can be utilized effectively in the following areas (Chidambaram et al., 2022):

- Injury Prevention: Wearable technologies play a crucial role in helping athletes and individuals engaged in physical activities reduce the risk of injury. The data collected can be used to identify abnormalities in the body or early signs of potential injuries.
- Performance Optimization: Athletes can use wearable devices to optimize their training and performance. The data gathered can be used to tailor training programs, leading to improved results.
- Game Day Optimization: Wearable technologies assist athletes in optimizing their performance on game days. The data enables players to manage their energy levels and make strategic adjustments.
- Post-Injury Diagnostics: Wearable devices aid athletes in tracking their recovery progress after injury and provide healthcare professionals with valuable information.
- Rehabilitation: Wearable technologies can monitor the rehabilitation process and provide data to physical therapists, enhancing the effectiveness of rehabilitation programs.

The use of wearable technologies in these areas is an indispensable tool for enhancing the health and performance of athletes, preventing injuries, and achieving superior results.

THE COMMON FUTURE OF SPORTS AND AI

The close collaboration between sports and AI is fundamentally transforming the experiences of athletes and fans, reshaping the future of sports. The widespread application of AI in sports is expected to continue growing. Nevertheless, as technology permeates all aspects of sports, there is a concern that the industry may lose some of its inherent charm while ensuring fairness in decision outcomes. It is worth noting that certain 'imperfections' in sports competitions contribute significantly to their allure. Therefore, there is a need for extensive and thorough research to ensure the scientific and judicious application of AI in sports (Ding, 2019). In particular, concerns are raised regarding excluding the human element, cost implications, and potential errors.

Critics argue that replaying games can disrupt ongoing competitions, potentially hindering certain offensive strategies. While implementing these intricate AI systems can minimize human error, they can also pose

significant financial burdens on less affluent sports federations. Suggestions for the judicious application of AI in sports include (Ding, 2019):

- Clearly defining the roles and responsibilities of governments and sports departments, along with bolstering policy and financial support.
- Elevating the standards for smart product applications in sports and promoting fairness.
- Establishing rigorous standards for data representation and information in AI sports.
- Enhancing the training of sports personnel and their proficiency in AI applications.
- Actively promoting high-quality AI capabilities and optimizing the seamless integration of production, education, and research.

The convergence of sports and AI plays a pivotal role in shaping the future of sports. The combination of sports and technological innovations promises to deliver a more efficient, effective, and enjoyable experience. However, amidst this transformation, it is crucial not to overlook ethical values and the human factor. While the integration of AI promises to provide unforgettable moments for athletes and fans, this evolution must be managed with a balanced approach.

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Chapter 3

Image-Based Recording and Analysis Methods for the Assistance of Track and Field Coaches to Improve Athletics Training

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Iraklis A. Kollias[2]

Abstract

The aim of the present scoping review was to present the image-based analysis methods that have being utilized to assist Track and Field coaches to observe the technique of their athletes aiming towards the optimization of performance. From the era of early photography till the current innovation of markerless motion analysis, sports and track and field athletes in particular are the field where the technological advances in image capturing and analysis are implemented for both practical, as well as for scientific purposes. The outcome of the blending of technology and sports science is the better understanding of human motion, the exploitation of its movement abilities, and its ideal segmentation when teaching sport techniques that has led to the optimization of sport performance and the identification of the unique prospects of human performance as presented by elite athletes. The chapter is comprised by a short description of the evolution in motion analysis methods, its contribution in the understanding sport techniques, its exploitation to create tools to effectively teach sport technique, and the presentation of the technological innovations that will assist track and field coaches in the future.

INTRODUCTION

The repetitive, commonly acknowledged manner in which forces are applied in relation with the way the body and its segments move in

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the environment to achieve a specific task is called technique of human movement. While there is a common format for the movement in each sport, an athlete's technique is not something predetermined, common and stable, but something that is constantly changing, depending on the phase of his athletic development (Kollias, 2019).

The teaching of sport techniques in Physical Education, the daily practice in athletics training, as well as for scientific research in sports provoke certain challenges, such as:

- the understanding of the mechanisms involved in the movement of the human body,
- the manipulation of these mechanisms aiming to improve the movement of the human body in the environment,
- the exploitation of the positive effects and/or the minimization of the disadvantages when the human body interacts with the environment,
- the definition, the identification, and the classification of the factors comprising the effective pattern adopted by "talented" individuals that result in the optimized execution of the movement.

The search for the answers in the above questions is suggested to trigger the process to teach sport technique in a way that others could adopt or personalize these factors in order to achieve enhanced performance by executing the desired movement in an efficient manner (Kollias, 2019).

METHODOLOGY

METHODOLOGICAL ASPECTS OF SPORT TECHNIQUE TRAINING

Techniques in athletics are complex. It has been suggested that for effectively teaching novices an athletic technique, simple deterministic models should be constructed depicting the basic features of the event (Dick, 1992, see an example in Figure 1). The simplest descriptive model of sport movement takes the form as a simple description. e.g., in the long jump "the athlete runs - steps on the take-off board - jumps - lands with his feet on the sand pit" (Kollias, 2019).

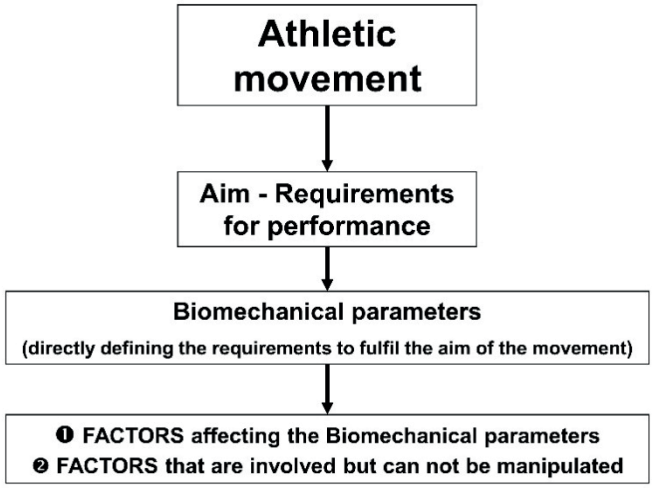


Figure 1. Flow chart of the elements to construct a deterministic model (adopted from Kollias, 2019).

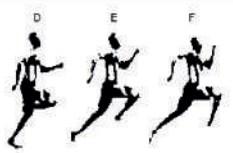
The visualization (commonly in the form of demonstration, Rink, 2006; Silverman, 1991) and feedback (Gallahue & Donnelly, 2003) are embedded in the learning process. Due to the complexity of athletics technique, errors are common. Thus, their identification and actions to correct them are essential in the training process. Error analysis is a process that includes movement observation and error analysis, as well as the identification-interpretation-correction of technical errors by the coach (Martin, Carl, & Lehnertz, 1993). For this reason, effective methods to ensure an objective control and error correction are necessary (Matveyev, 1981). However, the high speeds at which the movements of the body parts are carried out to perform the sports technique have made the use of visual media an essential training tool (Tidow, 1989). Athletics coaches are highly recommended (Schmolinsky, 1983) to present a series of photographs or films, both for learning and for the evaluation of their athletes' technique. Recent research revealed that this approach is effective (Kyriakidis et al., 2022a; 2022b). Nevertheless, the implementation of the results of biomechanical reports of elite athletes to novices or lower-level athletes without "filtering" this information through the model depicted in Figure 1 is not the most appropriate approach to effectively use the image-based information in the training/learning process.

For the aid of the coaches in practice, the concept of Model Technique Analysis Sheet (Figure 2) was proposed (Tidow, 1989). The Model Technique Analysis Sheet is comprised by the structure (namely, the phases

of the technique) of the movement with the corresponding illustrations (sketch or photograph) and a short description (containing the appropriate criteria) of the ideal technique (Tidow, 1989). A phase of the technique is defined as a complete movement that begins at some characteristic time instant, ends at another characteristic time instant and has a specific purpose, with the above being common to all (e.g., the approach in the long jump - Kollias, 2019). An important factor for the efficient use of the Model Technique Analysis Sheet is to provide the ability for immediate feedback and for iterative execution based on a goal. For this reason, the description of exercises and criteria must be clear, with short sentences and simple-to-understand terminology (Panoutsakopoulos & Kollias, 2008). For the construction of criteria assessment form, suitable for the evaluation of the phases of the technique, the following steps are required (Ferro Sánchez & Floría Martín, 2007, Panoutsakopoulos & Kollias, 2008):

- the collection of information regarding the movement,
- the definition of the aim of the movement in terms of an objective evaluation,
- the distinction of movement into distinct, separate phases,
- the determination of the biomechanical parameters fulfilling the aim of each phase,
- the identification of the critical elements used by coaches to improve the technique their athletes,
- to match the coaches' critical elements with specific biomechanical parameters,
- to set the evaluation criteria for each variable
- the determination of the form of documenting the results of the observation.

MODEL TECHNIQUE ANALYSIS SHEET 2.1: SPRINT RUNNING

SPRINT RUNNING	PHASE	CODE	REFERENCE	CRITERION ASSESSMENT
	(1) FRONT STANCE PHASE	AB1	Lead leg	Active movement downwards/"*pawing motion*"
		B2	Lead foot	Compliant support/"*active*"
		B3	Foot	Touchdown at the front part/near the projection of the body center of mass (BCM)
		C4	Heel	Recedes slightly/no ground contact
		C5	knee	Slight flexion
		C6	Hips	Fast movement over the stance point
		ABC7	Torso	Almost vertical (forward lean 5°-10°)/Torso, head and shoulder muscles: relaxed
		ABC8	Upper limbs	Contralateral swing in the sprinting direction/ elbows: 90° flexed/movement is generated from the shoulders
	(2) REAR STANCE PHASE	DE9	Support leg	explosive push-off/effort to avoid great vertical BCM displacement
		DE10	Support leg	Ankle, knee, and hip joints extend
		F11	Support leg - knee	Not fully extended
		DEF12	Duration of impulse	The shortest possible
		DEF13	Torso	Almost vertical (forward lean 5°-10°)/Torso, head and shoulder muscles: relaxed
		DEF14	Upper limbs	Contralateral swing in the sprinting direction/elbows: 90° flexed/movement is generated from the shoulders
	(3) REAR SWING PHASE	GH15	Rear leg	Movement forward and upwards/relaxed
		HI16	Knee	Flexed
		I17	Heel	Near the glutes
		GHI18	Swing leg	Fast swing forward
		GHI19	Torso	Almost vertical (forward lean 5°-10°)/Torso, head and shoulder muscles: relaxed
		GHI20	Upper Limbs	Contralateral swing in the sprinting direction/ elbows: 90° flexed/movement is generated from the shoulders
	(4) FRONT SWING PHASE	J21	Swing leg - thigh	Fast upward lift
		K22	Swing leg - thigh	15°-25° lower than the horizontal level
		KL23	Swing leg - shank	Fast forward movement/relaxed
		KL24	Swing leg - foot	Fast forward movement/relaxed
		L25	Swing leg - thigh	Downward movement/preparation for active landing/movement is generated from the hips
		L26	Swing leg - shank	Downward movement/preparation for active landing/no kicking action
		L27	Swing leg - foot	Downward movement/preparation for active landing/toes point upwards
		JKL28	Torso	Almost vertical (forward lean 5°-10°)/Torso, head and shoulder muscles: relaxed
		JKL29	Upper limbs	Contralateral swing in the sprinting direction/ elbows: 90° flexed/movement is generated from the shoulders

This Model Technique Analysis Sheet was created based on Kantzilis & Papaiakovou (2000) and Saraslanidis (2007)

Figure 2. Model Technique Analysis Sheet (with permission from Panoutsakopoulos & Kollias, 2008).

The main advantages of the creation of Model Technique Analysis Sheet for the evaluation of the techniques are (Ferro Sánchez & Floría Martín, 2007; Panoutsakopoulos & Kollias, 2008):

- the "translation" of the biomechanical parameters into "coaching language",
- the objective evaluation of the technique,
- the ability to gather all the information that exists in the literature, thus contributing to the provision of new solutions to a specific movement problem,
- the possibility of choosing goals for conducting the training/learning process with the method of mutual teaching and the method of self-control,

- the possibility of using the Model Technique Analysis Sheet to apply interdisciplinarity in the training/learning process (e.g., understanding the factors that influence the long jump and what kind of training should be done through the retraction of the principles of Physics taught in Education).

From the above, support is provided to the argument that images that are recorded either as photos or as videos or even extracted from image-based recording and analysis systems are of importance for the training process in track and field and, consequently, in the augmentation of performance in the athletics events.

METHODOLOGICAL ASPECTS OF IMAGE-BASED RECORDING AND ANALYSIS METHODS

A vast percentage of the obtained information obtained by humans are images and technology aids the perception of information in a direct and objective manner (Xu & Chen, (2022). It is not paradox that contemporary scholars study and debate on the identification of the track and field techniques in the antiquity using as reference the sport related depictions of ancient athletics that serve as artistic work on ancient amphoras, kylixes, kraters, tondoes, cups, etc. - Maras, 2017; Mouratidis, 2012).

There is a variety of both measurement systems and analyses methods. However, the instrumentation to record and analyze athletics techniques should be affordable, valid, reliable and objective (Kollias, 2019). Regarding the analysis methods, it is extremely difficult to conduct analysis during an athletics event using image-based analysis methods, as the instrumentation should be placed in locations not interfering with the competitors and judges, the calibration procedure cannot be conducted during the event, the environmental factors may not favor the recording, and athletes might not consent to the measurement. Under this perspective, the image-based recording and analysis methods are epigrammatically presented.

Photography

Initially, photography is the exact representation of an object that is depicted on a light-sensitive material in the form of an image (Kollias, 2019). Nowadays, digital photographs are created by computer-based photoelectric and mechanical techniques that exploit the arrays of electronic photodetectors of the digital cameras. As digital cameras are embedded in smartphones, digital photography can be considered as the most affordable image-based recording and analysis method for assisting coaches to capture, evaluate, identify the technical errors and provide feedback related to the

technique to their athletes. Nevertheless, the use of photography to assess athletics technique is replicating the same problem to coaches as scholars studying sports in antiquity: the still image can be circumstantial and random at the same time, thus depriving the opportunity to either get the information for the specific phase of the technique or getting an abstract segment of the desired information (Figure 3).

Figure 3. Single photo of middle distance runners. For the leading runner, the flight phase is recorded. For the trailing athlete, the instant before the midstance is shown. If the case was to study the runners regarding the technique elements of the push-off phase and to assess their technique using a Model Technique Analysis Sheet, this photo was not depicting the desired information for both runners.

The problem imposed by the single photography can be partially solved by using either the continuous shooting mode (mentioned also as burst shot) or using strobe photography. The former allows the recording of multiple images at once. This enables the capability to acquire images containing the desired depiction of the technical elements of interest with a greater chance (Figure 4). An early example of this concept by Eadweard Muybridge in the 19th century can be viewed at http://en.wikipedia.org/wiki/Eadweard_Muybridge.

Figure 4. Images acquired using the continuous shooting model (60 pictures/s; this synthesis contains every 15th photo taken).

The strobe photography is the blending of photos depicting the movement into a single image (Figure 5). It can be created by either merging a series of continuous photos by overlaying all the photos in one, or either capturing an image using a device commonly called as strobe, which is used to produce regular flashes of light, giving the impression of acquiring the movement in slow motion. This photographic technique was developed in the 1930s and required the execution of the movement in a dark room where strobe lighting was periodically illuminating the place by flashing up to several hundred times/s (Kollias, 2019). Beside the awkwardness to perform an athletics technique in a dark room, the frequent alterations of darkness and bright flashing could result to discomfort, disorientation, and consequently, to injury.

Figure 5. Strobe photography of the hurdle clearance. As the markers are placed in pre-defined positions, spatial parameters can be extracted. Also, joint angles can be measured. This strobe image was created using the APAS Wizzard v.1.2.59 software (Ariel Dynamics Inc., Trabuco Canyon, CA).

Another strobe photography technique used in the past was to attached lights (i.e., "active markers") on specific joints and to record, via continuous photos, their trajectory. This technique required capturing images in dim light or a dark room, a "slow" photographic film (i.e., 16-19 DIN) and batteries attached to the body (Kollias, 2019). All these factors again result in discomfort and to the inability to perform the technique optimally. Finally, a disadvantage of the strobe photography by blending the continuous photos into one is that the background should not be altered during the capturing of the series of photos. In addition, although the fact of capturing the technique in more time-instances, the same limitation as the single photograph applies, as it is possible to miss recording the desired image. Blending additional images from the series of continuous photos might not solve these mishaps, as then the image gets blur due to the overlaying the images on each other that eventually results to the difficulty to identify the body segment with the corresponding time instance.

In general, due to the disadvantages and the limitations of the photographic methods to capture and to analyze athletics technique, their usage is limited for qualitative approaches or artistic depictions of sport movement.

Cinematographic- and video-recording methods

The motion-based analysis methods are based on the fact that the recordings accurately capture the movement in a predetermined rate (Kollias, 2019). Thus, the motion can be "freezed" and a detailed observation can be conducted by the frame-by-frame viewing of the recordings. In addition, the basis of these methods, namely the spatiotemporal depiction of the recorded movement, provides the ability to conduct a kinematical analysis on the planar plane (2D) or even in the 3D space (Figure 6).

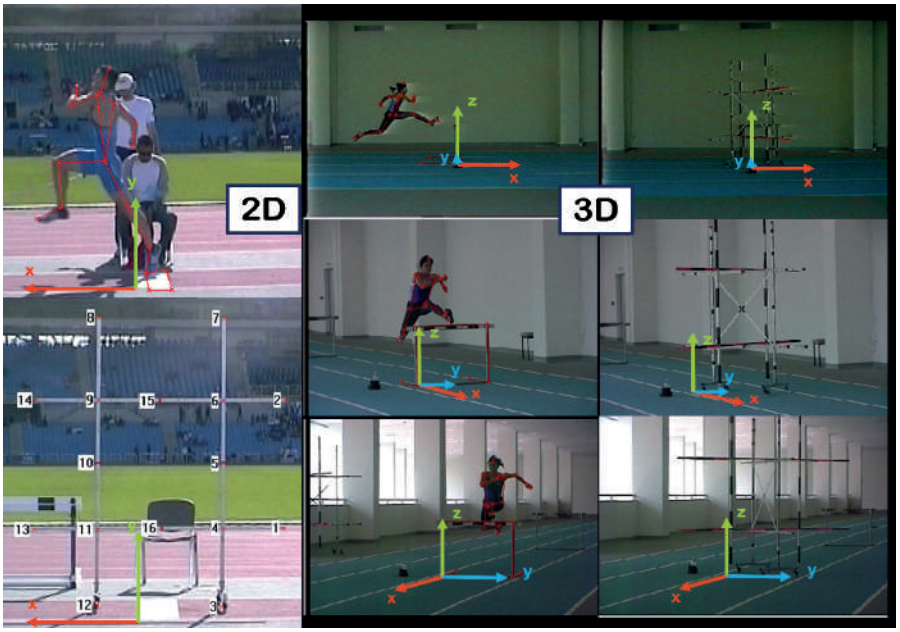


Figure 6. Views, axis of movement and calibration for 2D-DLT and 3D-DLT kinematic analysis.

As a furhter technological step to the work of Muybridge, cinematography was used. The main advantages of cinematography compared to photography was the increased sampling frequency, the resolution and the ability to study the athletic technique as it evolves spatiotemporaly. At first, their sampling frequency was not satisfactory, but this was improved over time. Nevetheless, there were some disandvantages: i) the motor that rotated the film to capture high-speed cine-film was noisy and this imposed possible troubles when recording athletes in competition, ii) there was no instant reviewing of the captured film (i.e., if the view of recording recorded the whole ranged of the motion of interest), as the film could not be developed on cite, and iii)

the analysis of the recorded film required additional equimpent such as the projection machine and the digitizer (Kollias, 2019).

To overcome some of the above-mentioned problems that characterized the cinematographic recording and analysis of athletics technique, the video-recording method emerged in the 1980s. It was cheaper, more user-friendly and less time consuming in terms of the time-gap from recording to the initiation of the analysis (Kollias, 2019). At first, the resolution of the recorded videos and the size of the depicting object of interest in the image were lower than the cinematographic method and researchers debated whether the video-based analysis techniques were comparable in terms of accuracy to cinematographic methods (Angulo & Dapena, 1992; Kennedy, Wright, & Smith, 1989). The technological innovations regarding the improvements in the resolution (both in the recording camera and the display screen for the digitization) and the sampling frequency, besides the elimination of the barrel-like distortion of the image with the use of flat screens, led to the abandonment of cinematography.

Along with the technological innovations, researchers developed techniques to record and analyze athletic movement not only with stationary cameras, which is the standard method to conduct the recording and the analysis of sports movement, but with panning cameras (Figure 7) as well (Gervais et al., 1989; Yu, Koh, & Hay, 1993).

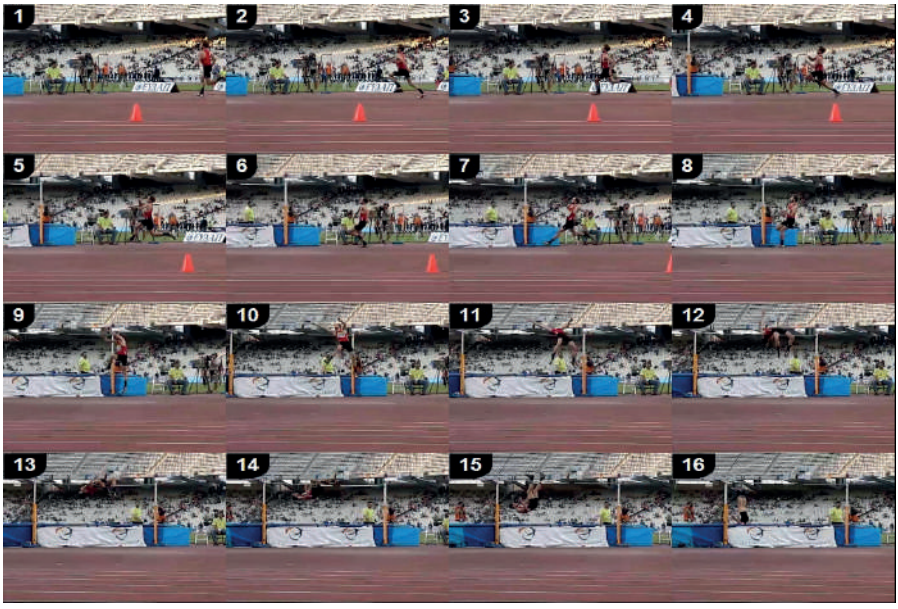


Figure 7. Summary of a video recorded with panning technique. The sequence was created using the Kinovea 0.9.4 (©2021: Joan Charmant and the Kinovea Community) software.

Motion analysis systems

As already described, the imaged-based recording and analysis methods are related to the technological advances. One such advance was the introduction of optoelectronic motion capture systems. A series of sophisticated cameras that emit invisible infrared light trace constantly within the recording space (i.e., "volume") the reflective markers (i.e., "passive markers") that attached to the object/examinee at predefined points (Figure 8). The coordinates of these points (joints and segments) are automatically stored in a computer. Then, the motion analysis system provides an estimation of the position and pose (orientation) of the examinee across image sequences. The greatest advantage of the motion analysis systems is that the kinematic parameters that interpret the examined movement is almost immediately available (Kollias, 2019). This is because of the automatization of the system compared to the manual, field by field, digitizing of the anatomical points and other markers of interest in the cinematographic- and video-recording methods (Colyer, Evans, Cosker, & Salo, 2018).

Figure 8. Reflective marker positioning on a participant in a pilot study using an optoelectronic motion analysis system in an indoor track. The study examined the resisted sprinting biomechanics when pulling a weighted sled.

Despite the disadvantage of the possible marker misalignment with the joint in the case of rapid movements, the accuracy of the optoelectronic motion capture systems is documented (Richards, 1999; Topley & Richards, 2020) and found to be superior compared to other motion analysis systems (Van der Kruk & Reijne, 2018). However, the optoelectronic motion capture systems are mostly designed for the indoor measurements of

slow movements conducted in a limited space; all circumstances that are not characteristic of sport (Van der Kruk & Reijne, 2018) and track and field in particular. In addition, these systems cost considerably higher than the previously mentioned analysis methods. Among other disadvantages, markers need to be attached on the athletes with the above-described discomfort, resulting in limited use of this method during competition. In addition, a considerable time to prepare the examinee is required in order to attach the markers (Colyer et al., 2018).

Markerless Motion Analysis Systems

The latest innovation in the field of image-based recording and analysis methods is the automatic, non-invasive, markerless motion capture systems. An advantage of the markerless motion analysis systems is that there is no use of markers that may provoke discomfort and disturbance in the execution of the sport technique (Kollias, 2019). Another advantage is the availability to retrieve information both indoors and outdoors, during training and competition, in testing and in general in any aspect of the training procedure. The major elements of a markerless motion analysis system are the camera systems, the body model, the image features used and calculation (algorithms) of the shape, pose, and location of the object of interest. However, in order markerless motion analysis systems to provide accurate results, the same mishaps are recorded alike the optoelectronic motion capture systems, added the high-resolution cameras required to assist the identification of the body segments. Readers are referred to the work of Colyer et al. (2018) for an in-depth presentation of this technology.

RESULTS

Regardless the image-based recording and analysis method, coaches can be benefited by retrieving both qualitative and quantitative information.

Qualitative analysis

In terms of the qualitative assessment of athletics technique, coaches can compare the image(s) depicting their athletes with the ideal technique presented in a Model Technique Analysis Sheet.

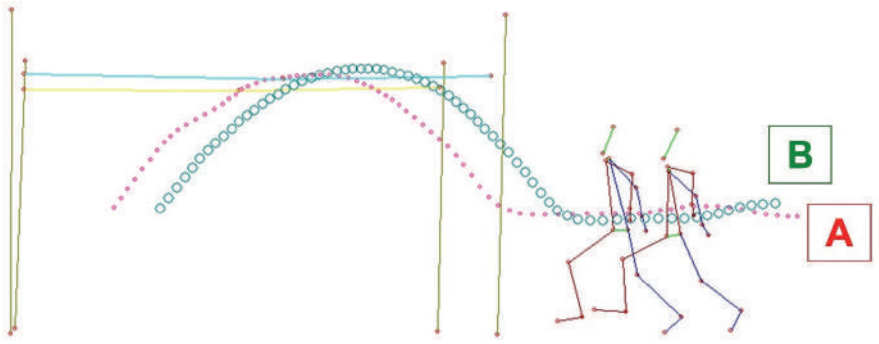


Figure 9. Stickfigures of the same high-jumper in a longitudinal biomechanical analysis of his technique. The 3D-DLT analysis was conducted using the APAS v.14.1.0.5 software (Ariel Dynamics Inc., Trabuco Canyon, CA).

In this concept, not only a picture, but also a stick-figure, either by itself, or over-imposed with another stickfigure (Figure 9) and/or on a captured image of the athlete's technique (Figure 10), could add details in the information provided to the coaches. It can be also a useful tool to provide feedback to his/her athletes.

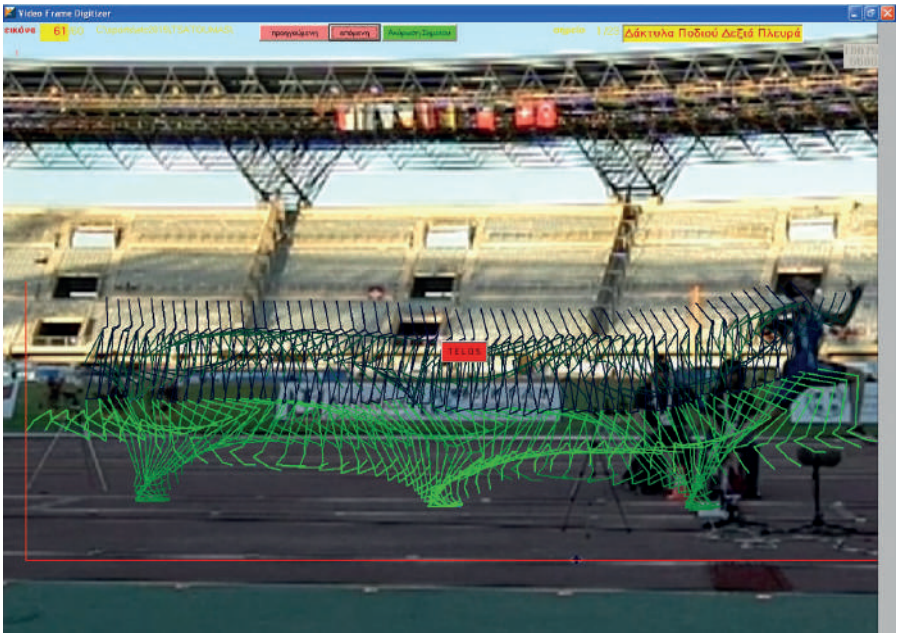


Figure 10. Stickfigure imposed on a field of the video used to conduct the 2D-DLT analysis using the K-Motion v.15 software (Kinvent, Orsay, France).

Quantitative analysis

When considering the quantitative information that can be given to track & field coaches, kinematic analysis can take the form of presenting values in a form of a table, graph, and/or combined in an infographic material (Figure 11). In addition, the results can be depicted in graphs in relation with previous results of the same athlete or other athletes for a comparison and ranking. Another form of presentation is the time-curve of a parameter of interest. Finally, the deterministic model as presented in Figure 1 can be enriched by providing the correlation/regression scores of a certain athlete after analyzing a cohort of his/her attempts (Figure 12).

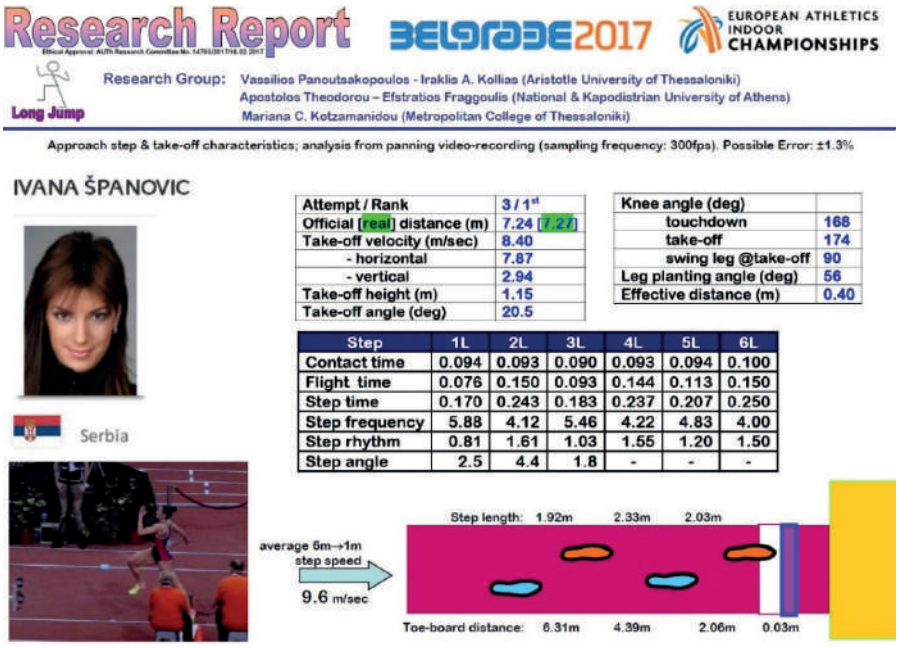


Figure 11. Summary of a qualitative report of a video-based kinematic analysis conducted for attempts performed in a major athletics competition.

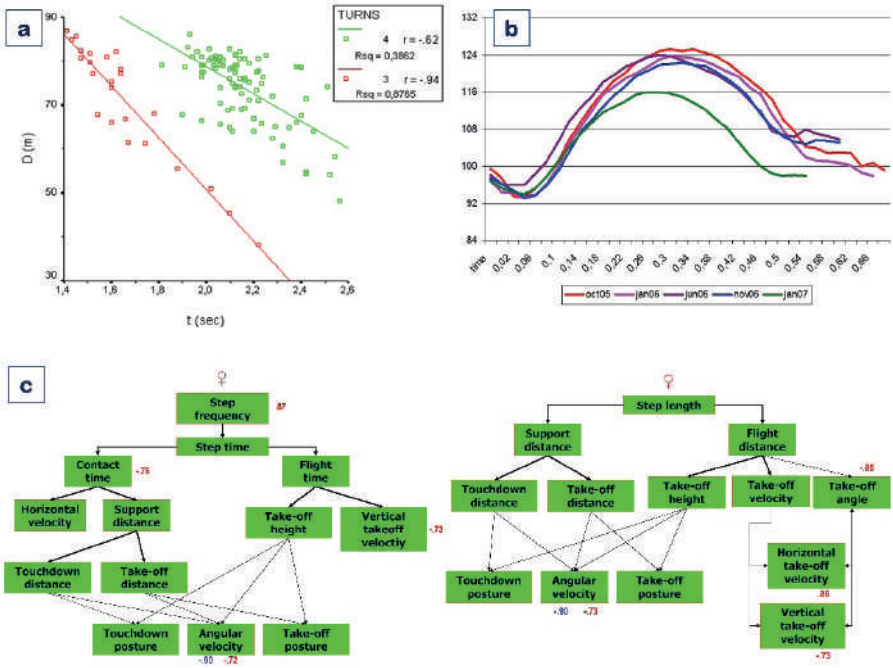


Figure 12. Forms of providing quantitative information to coaches: a) comparison and ranking of hammer throw distance related to the duration of the throw, b) longitudinal time-curves of the body center of mass height during the hurdle clearance of a female hurdler (84 cm hurdle), and c) correlation coefficients of the factors comprising a deterministic model for sprinting (adapted from Hunter, Marshall, & McNair, 2004) with the 100 m sprint times of a female sprinter.

DISCUSSION

The image-based recording and analysis methods are beneficial for monitoring the evolvement of the athletics technique and can contribute to the augmentation of performance by optimizing the biomechanics of the sport movement, as well as by identifying technical errors with the potential risk of the ineffective exploitation of the athlete's capabilities or/and of provoking an injury. The technological advances provide affordable innovations and accurate instruments, with multidisciplinary applications that assist coaches to optimize the training process.

Despite the world-wide growing use of image-based recording instruments primarily among the track and field coaches' community and secondarily the seek for scientific evaluations with image-based analysis systems, some factors should be indicated for the optimal selection of the approach to acquire the desired information (Kollias, 2019):

- the trajectory of the movement: a basic analysis of the horizontal jumps and the sprinting/running events consider the movement as linear, thus just a camera is used and a 2D kinematic analysis is adequate to retrieve the desired information. However, if a large series of strides is the topic to retrieve useful information, then additional cameras are needed. In addition, if a rotation of the body or of a body segment or of an implement occurs in another plane of motion, then the technique in question should be examined with a 3D kinematic analysis, in which at least two (2) cameras are required. These alterations result in differences in the cost of the analysis and the time required to obtain the necessary results.
- the speed/frequency in which the movement is performed: the sampling frequency of the image-based capturing system should be in alignment with the duration of the investigated technique phase. For example, the support phase and the take-off in the sprint, jumping and high-hurdles events ranges from 0.08 to 0.18 s. Thus, the evaluation of the technique at this phase requires and adequate number of images. The common mobile phone camera's sampling frequency is 30 fps. In the above-mentioned example, this image-based capturing system can record just 3 to 6 images that are rather a small sample to extract accurately kinematic parameters such as linear velocity. Thus, a more specific and advanced camera is needed, that is more expensive, along with a reliable image-based analysis system.
- Recordings can be conducted during practice, but preferably during competition, where is believed that the optimization of performance occurs (Christensen, 2004). The successful recording assumes the knowledge of the proper settings of the motion analysis system, the avoidance of any obstructions in the field of view of the recording camera(s), and the effort to keep the background as neutral as possible.

Another topic is the compatibility of the image-based recording and analysis system with other measuring instruments, i.e., force-plates, electrodes for electromyography, spirometer, electrogoniometers, inertial measuring units, etc. The holistic approach of the examination of sport performance, although intriguing when multiple factors are considered, provides an ecological depiction of the concurrent status of the athlete and thus valid feedback for both coaches and practitioners.

To conclude, it is not an exaggeration to suggest that image-based recording and analysis methods are the basis for the introduction, progression, and maximization of performance in athletics via the visualization of the

technical execution of the specific athletics technique, since humans are based on visual information to perceive. At this point, a couple of facts should also be mentioned. Firstly, despite the major importance of visual cues in athletics, an alternative approach should be followed when training visually impaired athletes, despite they were found to perceive time-to-contact to the take-off area regardless of the level of visual acuity (Panoutsakopoulos et al., 2015). Secondly, technology is rapidly involving in other measurement and assessment technologies such as inertial sensory, ultrasonic localization, and electromagnetic measurement systems (Van der Kruk & Reijne, 2018). Although different technologies compared to the motion analysis systems, their feasibility and affordability could add tools from which track and field coaches could benefit.

Acknowledgement

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Chapter 4

Wearable Technology Usage in Race Walking

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Abstract

The use of temporal sensor data related to human activity has greatly increased in recent years thanks to smart technology has become widespread and even ubiquitous in our daily lives. Today wearable technology has many roles in our daily life. Wearable technological products allow us to easily obtain a lot of data in the field of sport and health. This data can make it possible to monitor physical condition, athletic performance, training load and can even be used to prevent injury mechanisms or to analyze rehabilitation. Athletics is one of the sports in which performance is tracked metrically and chronometrically. The only exception is race walking which based on subjective observation of the judges in this sport. There is a need for the development and use of wearable technological devices that can support referee judgment in walking and can be used for fair decisions in disqualification and penalty time applications during the competition.

INTRODUCTION

It is very important to analyze the role of wearable technology in daily life and why there is such a need for that devices, it is known that there is a need for this technology from different groups. Wearable technologies are innovative products which created with the help of technology and can be considered as one of the most important technological elements of the 21st century. Today, there are products which are sometimes integrated into clothing or accessories and at the same time have information and communication technology. These products can store data or transmit the data to smart devices via the smart sensors in their systems. Wearable technology products and the markets of it's are developing together with many disciplines and connected with needs. In addition to important areas such as health, education, production and security, wearable technological products are also used to follow the activities of everday life (Çakır et al.

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2018). The first examples of wearable technological products emerged in 1884. The first products of wearable technolgy were created by adding led lamps to ballerina tutus which called Electric Girls are considered to be the pioneers of wearable technology. Not every product used in today is considered as have wearable technology features. Trackers of wearable technologies can help motivate you during workouts. Together with your smartphone they can track and inform you about your daily routine or fitness, without requiring potentially annoying manual calculations or recordings(Kaewkannate & Kim 2016). In order for a product to be a wearable technology, it must transfer the data collected for a specific purpose through smart sensors through an integrated system to the technological product developed by bluetooth or any wireless means (Çakır et al. 2018) Wearable technology products specialized electronic tracking which are designed as devices synchronized with a computer or smartphone to provide long-term data tracking, in most cases wirelessly., Smart sports products such as Rings, smart glasses, smart watches, wristbands or bracelets, smart helmets, smart t-shirts, smart gloves, smart socks, smart shoes and many more collect information during the athlete's training activities and store or transmit this information internally. These products are state-of-the-art mini computers that can be worn and integrated into various parts of objects in different ways (Kaewkannate & Kim, 2016). Smart sports equipment generally consists of a wrist-worn device and sensors that store the user's activities on mobile devices. With sports specialized smart products, the user measures some values such as temperature, muscle activity, sweating amount, body fat ratios thanks to the sensors inside and reports the result to the user. One of the biggest benefits of these products is what they provide the user with very detailed information about the sport. They monitor, record and regularly track all types of actions, from musculoskeletal system actions, as blood pressure and heart rhythm values (Kaewkannate & Kim, 2016), (Çakır et al. 2018).

With the appearance of wearable devices such as phones and tablets, the accessibility of temporal sensor data related to human activity has greatly increased. Therefore, the fields of human activity recognition (HAR), intelligent monitoring, human-computer interaction and video capturing based on wearable devices have also attracted more attention (Wang et al., 2023). In many sports, team sports, water sports, snow sports and of course individual sports such as running, cycling, triathlon, etc., wearable technological devices have become one of the safest ways to monitor the trainings (Chambers et al., 2015). Motion capture is used in sports performance to analyze physical condition, athletic performance, technical

expertise and injury prevention mechanism or rehabilitation. Inertial measurement unit (IMU) and Global Positioning System (GPS) sensors are mostly found in wearable sports devices, but other features can be programmed for different needs (Adesida et al., 2019). The general demand from users is for a combination of wearable technology and aesthetics; products that are sleek, modern and lightweight, with unobtrusive designs, waterproof and with versatile functionality, and multiple options for charging the battery are the most preferred. High accuracy in tracking the physical parameters of these technological products for simple activities such as climbing or descending stairs and healthy monitoring of vital parameters (heart rate, pulse rate, body temperature, respiration or others) are the main features expected in a smart device (Kaewkannate & Kim 2016).

Another system that is needed especially in professional sports is motion analysis systems, particularly in the last 30 years, with the development of cameras, computer science and image processing technology, these systems have started to become widely used in sports. Especially in sports, wearable sensors with different nature have a variety of uses, which are useful in many ways. The function of wearable technological devices in our lives is increasing day by day, and by integrating technology into sports, users have the opportunity to collect more data about their technique and performance. Feedback on an athlete's performance plays a huge role in success. Today, the field of wearable technology is very wide and each of them is thought to have its own role to play in different sports and industries (Adesida et al., 2019). Wearable technological devices have many uses in the field of sports performance; motion capture is used to analyze athletes' physical condition, performance, technique and the underlying causes of injuries. At the same time, technological devices are used to monitor and record human movements in order to analyze rehabilitation as well as injury prevention (Ortega & Olmedo 2017). Microtechnology has allowed sports scientists to understand locomotor demands in various sports. While wearable global positioning technology (GPS) is widely used to measure the movement-related demands of activities in line with the needs of the respective sport, sometimes microsensors integrated into the units (i.e. accelerometers, gyroscopes and magnetometers) are also capable of detecting sport-specific movements (Chambers et al., 2015).

Sports research often requires capturing human movement of an athlete. Human motion capture is the process of recording human movement; the system mostly focuses on recording the global position of (segments of) an athlete's body (Van der Kruk & Reijne 2018). Both coaches and athletes can benefit from performance monitoring and objective feedback using

technological devices as a method to monitor and improve their athletic performance, while minimizing the possibility of injury. The traditional observation technique and approach used by the coaches is based on their expertise, experience and background. Growing interest in technology and research is pushing this subjectivity further into the background; for example, video analytics, where videos can be annotated to measure angles, allows performance to be measured objectively rather than depending on the critical eye of coaches. However, such approaches provide objectivity and allow athletes to provide real-time feedback (Adesida et al., 2019). However, such approaches provide objectivity and allow athletes to provide real-time feedback (Adesida et al., 2019). The human body has reference systems; reference systems allow body segments to be positioned relative to each other and to the body in its environment. They facilitate the description and study of movement (Balthazard et al., 2015).

The study of movement, which is the nature of sport, has of great importance in each branch for the development of performance. Athletics is undoubtedly one of the most popular Olympic sports. Athletics is a main sports branch that consists of many sub-branches and always aims to renew records with the principle of faster, higher, stronger. Athletics is by its very nature based on objective data, and since its measurements are metric and chronometric, there is no room for doubt in the process of determining the champion. The only exception of athletics which has subjectively evaluated is walking. Race walking is an Olympic competition discipline considered to be the fastest expression of walking (Paveyi et al., 2012). A lot of work has been done since the 1980s for the kinematic analysis of race walking. Nowadays, technology in sport plays an important role in assisting training and evaluation processes .There is a need for technological equipments to support referee judgment in race walking competitions. Many studies in recent years have proposed the use of a wearable inertial system to derive new biomechanical indices for the assessment of performance and violations in race walking (Caporaso 2020).This study was conducted to inform the reader about the wearable technological products that are used and planned to be used in the race walking branch of Athletics, both for performance monitoring and to objectify the adequacy of the technique and to form the basis for the decisions of the referees during the competitions.

Wearable Technology in Sports

Wearable Technological Products Which Used in Athletics

The most commonly used wearable devices for walking and running in athletics: Nike, Polar, Suunto, Fitbit, Garmin, Apple, Misfit, Samsung Gear,

TomTom and Lumo and many other brands are also been used. With these devices, often data such as heart rate, step count, running-walking speed, exercise distance, energy consumption, metabolic analysis, sleep duration and sleep quality can be monitored. (Bunn et al., 2018). While there are many devices for tracking and sharing running and walking-based exercise routines, unfortunately these devices offer limited functionality for strength trainings. There are also some products that automatically track repetitive exercises such as weight training and calisthenics through an inertial sensor which worn on the arm (Morris et al., 2014). In sports, some applications of wearable technologies are useful tools to measure the athlete's performance in outdoor conditions and can therefore play an important role to support training. Moreover, because they can provide accurate and reliable data from athletes, they can also be used for the development of tools that can support judgments (Caporaso & Grazioso 2020). Some of these wearable products aim to monitor and record athletes' movements in real time (Pueo & Jimenez 2017). Nowadays 3D kinematics is a basic input data for many fields such as motor control, biomechanics or animation. However, the most popular opto-electronic systems using active or passive markers are based on fixed cameras and can only acquire a limited volume of data with this method. Human movement can be studied during several cycles (Begon et al. 2019). Motion capture systems have the capability to analyze many functional movements and sporting tasks from a biomechanical point of view. Optical systems consist of cameras and branch-specific systems to track passive or active markers placed on anatomical landmarks for full body capture. It has been reported that these systems are widely used in a series of different sports, from track and field to boxing, modern pentathlon, tennis, swimming and taekwondo (Krüger & Edelmann 2009). However, due to the required camera setup these systems often have quite limited capture volumes in to the laboratory environment. Furthermore, the large number of markers that were often needed had negative effects on timing. This may hinder a clear understanding of the performance of the tasks under investigation, and even conversely, the complexity of sporting tasks can often lead to confusion due to the markers and a blocking of the analysis process. Wearable technology is an alternative approach that has the potential to overcome these limitations. There are a number of different types of sensors, including Inertial Measurement Units (IMUs), which include a combination of magnetometers, accelerometers and gyroscopes, and Microelectromechanical sensors (MEMS). In addition, there are flexible sensors, such as those manufactured by Spectra Symbol (Salt Lake City, UT, USA), which can track joint motion through changes in resistance when a force is applied to the sensor (Adesida et al., 2019).

By processing and analyzing sensor data collected with HARs, it is possible to automatically detect activity types. The monitoring system has utilized HAR in many applications, including activity analysis, gesture recognition and user health monitoring. The development of smart devices has provided good opportunities for HAR based on wearable devices. Compared with computer vision-based recognition, HAR based on wearable devices has provided significant advantages such as low budget, high performance, and portability while avoiding the impact of video blind spots and insufficient illumination (Wang et al., 2023).

Another important advantage of these wearable systems is the ability to monitor athletes in a real sports environment to provide real-time feedback, a feature not provided by video analytics. It is also designed as a small, lightweight, wireless and inconspicuous device to allow for all movements during participation in a sport. This makes it possible to observe athletes outside the laboratory environment and in natural training areas. The sensors can be used in many sports such as swimming, mountain biking, skiing and snowboarding that take place in the extreme conditions and have additional features like being waterproof or able to withstand very cold weather and quite high temperatures while recording data (Adesida et al., 2019) However, along with the advantages of being wireless, it can sometimes be said to create some limitations: ferromagnetic objects in the environment can degrade the data quality and measurement values from inertial-based systems. Besides data accuracy, accurate positioning can also introduce errors when trying to estimate data input, acceleration measurements and positional data (Alonge et al., 2014). Furthermore, selecting a wireless method for data transmission may create the possibility of signal loss during recording or interference from cell phones or other devices which may be on the same transmission frequency (Reenalda et al., 2016).

Recent developments in wearable and wireless sensor technology allow for a complete ongoing 3D motion analysis outside the lab. Inertial sensors, also named inertial measurement units (IMUs) or inertial magnetic measurement units (IMMUs, devices that also include a magnetometer), have been successfully used for 3D walking analysis (i.e. walking) and have shown considerably better accuracy compared to optical motion analysis systems (Dejnabadi et al., 2006.; Roetenberg et al., 2007). Various inertial sensors are also used in sports science to consistently analyze the motion.

The process of capturing motion with wearable sensors can be a highly tedious and intensive process, and it can sometimes be challenging to obtain information about the accuracy and practicality of the measurement systems.

The features reported by the manufacturers are sometimes determined in different conditions and set-up conditions than the field and competition conditions in which the sports research is carried out; therefore, the sports research is carried out depending on four important characteristics of the field. First of them is; sport research is mostly conducted in non-laboratory settings, on the training field, track or arena where athletes play sports. Measuring in a space outside of controlled laboratory environments presents several challenges, such as the different locations of the indoor and outdoor environment, weather conditions, temperature, humidity, light differences, measurement interferences such as noise, scattering, magnetic disturbances, and obstacles that cause obstructions in the space (Van der Kruk & Reijne 2018). Second, the area and capture volume set for making measurements is usually large. Accuracy is therefore often inversely proportional to the coverage of a positioning system. That means the larger the measurement coverage, the wider the area, the lower the accuracy, which is often one of the main factors limiting the researcher in the choice of a measurement system. When participants' displacement increases during training or competition, ergometers are sometimes used to obtain a large number of movement cycles (Begon et al., 2009). (Van der Kruk & Reijne 2018) Third, research for sports analysis often deals with a wide range of sporting movements, from static or slow movements (e.g. walking analysis) to highly dynamic movements that are much more difficult to capture. For importantly, the requirement of high sample frequencies poses a technical challenge. Typical sample frequencies for sports applications are between 50 and 250 Hz. There is a preference to avoid the use of very high sampling frequencies to avoid excessive amounts of data and high frequency noise. Only in certain situations very high frequencies are required, for example to detect impact (such as during a jump) or to examine very high speed movements (>1000 Hz) such as a serve in volleyball, a shot in soccer or a baseball throw. Moreover, the system has to deal with motion dynamics, which poses some problems, for example, in inertial measurement units (IMUs), where linear accelerations can spoil the sensor position estimation of sensor fusion algorithms (Van der Kruk & Reijne 2018). Fourth, when a measurement system demands sensors, markers, transponders or tags to be placed directly on an athlete, the size and weight of the sensors are critical to ensure that movement can be performed with true speed and technique. Especially in high performance and high dynamic conditions, an athlete's freedom of movement should not be inhibited or minimally restricted (Van der Kruk, Reijne 2018).

Race walking from past to present

Race walking is a long-distance competition discipline that has been part of the Athletics competition program since the 1908 Olympics. These locomotor limitations have forced athletes to develop a characteristic pattern commonly known as the 'race walking style' (Pavei 2014), (Brisswalter 1998). The rules for this walking technique are clearly stated in the World Atheltcis Rule Book (Rule 230). Due to the high technical demands of the walking event, race walkers are under constant monitoring by referees during the races to ensure they comply with the rules (Harisson 2018). 'Race Walking is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs. The advancing leg must be straightened (i.e. not bent at the knee) from the moment of first contact with the ground until the vertical upright position' (IAAF 2016). Race walkers use a unique walking technique to optimize speed while following the rules.(Harisson 2018) Unlike other disciplines in athletics, race walking is the only discipline in all athletics disciplines where the human factor and subjective decisions are involved. Failure to comply with the rule that the athlete must not lose contact with the ground (a visible loss of contact) is a common rule violation in this sport discipline, especially at the elite level. It is called loss of ground contact (LOGC Loss of Ground Contatct). LOGC is defined as the time when the toe of the rear foot loses contact with the ground and the heel of the front foot touches the ground.

There should be no visible interruption between two temporal walking events. The movement must continue in a series of steps as shown in Figure 1.

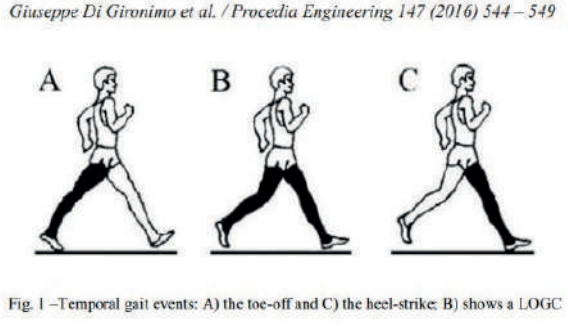

Figure 1) Steps of the race walk A) Foot off the ground B) Loss of contact C) Heel contact with the ground

In image B, the athlete's rear toe and the heel of the front foot are not in contact, showing illegal technique.

In the context of race walking, the main users can be considered in three contexts: athletes, the leading actors of the race; coaches, the "chief technical officers" of the athletes' team, responsible for the adequacy of performance and technique; and referees, the guarantors of the orderliness and fairness of the race. All these stakeholders are always interested in new tools to monitor sports technique in training and competition scenarios. Athletes are interested in receiving objective feedback about their performance and technique. Coaches are interested in having basic indicators of athletes' performance and violations, which are very useful for optimizing training and competitions, but also for developing new customized strategies. Referees are interested in useful tools to help evaluate violations during competitions (Caporaso & Grazioso 2020). For this reason, coaches focus highly on development, especially training aimed at developing specific motor behaviors. All this makes race walking a very technical discipline (Girnomio et al. 2016). Even a minor violation of this rule on the track can lead to the athlete being disqualified. The most common rule violation is the loss of ground contact (i.e. the flight phase). Race walking is an Olympic event in which athletes are not allowed any noticeable loss of contact and where competitors try to minimize their flight time as a result (Hanley 2019). Two main defects can be found in the visible observations of walking contest judges. First, the human eye can maintain an image gradation at 16 Hz. Therefore, a flight phase lasting less than 0.06 seconds cannot be detected by any judge. In addition, athletes usually compete in groups, it makes extremely difficult to track a single athlete during the race, also known as the theory of change blindness (Harisson et al. 2018). Secondly, the judges are located at different points of the race track and can therefore evaluate each athlete for limited periods of time. The direct consequence of these flaws is the presence of cases of missed violations or wrong disqualifications during each official competition. As a result, the credibility of this Olympic sport is gradually diminishing and its future inclusion in the Olympic Games is being questioned (Harisson et al. 2018).

Examples of Wearable Technology needs and Applications in race walking

In a field study evaluating race walking (Loss of Ground Contatct) in terms of LOGC (Loss of Ground Contact), it was observed that the results obtained were in line with the values obtained in laboratory tests. Both studies consider the acceleration system to be a useful as a tool for judges

to use in their measurement and decision-making process for loss of contact decisions during a race walking competition. In specific, the proposed data analysis protocol in combination with the inertial sensor is a valuable tool for identifying strides during a low-speed walking training session (it can be said that illegal strides are not very common in terms of the assessment of contact loss during the speeds obtained in slow-paced training). However, in cases where athletes reach high speeds in the competition pace, many contact losses occur, therefore, illegal steps were detected in the questions reached in the races. It is thought that this system will help coaches in training and referees in the process of evaluating athletes during the competition. Every athlete wants to win the race. It is much more difficult for race walkers to pick up the pace in the last few minutes of a race in major organizations where race walkers typically win with a negative pacing strategy and faster second-half times than first-half times. This challenge comes from the fact that athletes and coaches need to be careful with the important effects of technical limitations, since they have to follow the technical rules that regulate this discipline (Vernillo et al., 2012; Gironimo et al., 2016). In major walking events such as the 2011 IAAF World Athletics Championships and the 2012 London Olympic Games, 12% of race walkers were disqualified due to loss of primary ground contact or knee bending (Lee et al., 2013). In a study which conducted by Hanley, biomechanical analyses were performed on the flight time of athletes who ranked in their categories at the 2012 World Walking Championships. In this study, it was determined that each athlete has a flight phase that can be measured with milliseconds, although it is invisible to the human eye as the rule states. As a result of the biomechanical analysis, it is reported that athletes with longer step lengths have longer flight times and this creates a risk for disqualification (Hanley 2013).

Table 1: Table of flight times and cautions received by medalists in the 2012 Race Walking World Cup (Hanley 2013).

	Contact time (sec)	Flight time (sec)	Contact time (%)	Red cards (~)
20km Senior Women	0.26 (± .00)	0.03 (± .01)	88.7 (± 3.6)	0
20km Senior Men	0.26 (± .02)	0.05 (± .01)	84.7 (± 4.1)	2
50km Senior Men	0.26 (± .00)	0.04 (± .00)	86.7 (± 0.0)	0
10km Junior Women	0.25 (± .01)	0.04 (± .00)	86.3 (± 0.5)	3
10km Junior Men	0.26 (± .02)	0.04 (± .00)	86.6 (± 0.9)	1

It is important to note that loss of contact lasts for a tiny fraction of a second, so it is quite difficult to assess (reliably) using only human eyes, as

is often the case in current practice. The importance of this necessity is also underlined by the international federation (World Athletics 2023), which is interested in the conception of a new competition system (World Athletics 2023) capable of assessing contact loss, reducing judgmental problems and thus increasing the external trustworthiness of the race walk (Caporaso & Grazioso 2020).

Although loss of contact (or "time of flight") can solely be assessed visually during competition, research has been conducted on this topic using several different methodologies. The purpose of these studies is to support athletes during training and to provide quantitative measurements for referee training. These include work with standard video cameras, high-speed videography optoelectronic systems, power plates and an inertial sensor. Considering the importance of flight time measurements for race walkers and coaches (e.g. when comparing flight time between different periods of the training season), using a trustworthy system is essential in determining the actual duration of flight time (Hanley 2019).

In track conditions, four technologies are potentially available for the estimation of contact loss: high-speed camera, optical measurement systems, base pressure and wearable inertial systems. Video analysis using a high-speed camera provides a reliable assessment of sports kinematic parameters; indeed, some authors (Padulo 2015) have used this technology for the assessment of contact loss. However, video analysis requires intensive post-processing and is therefore difficult to use in real conditions (training and competition scenarios) where a continuous and real-time assessment is required. In summary, the main limitations of video analysis are that it is a time-consuming process and does not allow for continuous analysis of athletes, especially when athletes are in groups. More recently, optical measurement systems (i.e. the OptoJump Next system) have been used for race walking analysis, demonstrating how this system can be used to provide highly reliable values for the evaluation of contact loss timing in elite race walkers and in on-ground and treadmill testing (Hanley 2019). This technology allows for faster assessment of contact loss compared to video analysis. However, even this technology is difficult to use in real training and competition scenarios as it requires the athlete to walk alone and only allows analyzing a few steps. Many researchers have proposed different systems for automatic detection of illegal steps in walking competitions. The first use of inertial sensors in race walking can be traced back to the work proposed by Lee et al. In this study, Lee et al. estimated the flight time with a formula derived from the analysis of the vertical acceleration curve and reported that only one linear accelerometer placed on the S1 vertebra

was successful in detecting contact loss errors with a sensitivity of up to 88%. Santoso and Setyanto conducted a study by placing a piezoelectric transducer they developed in their research on the shoes of hikers. In this study, they enabled real-time detection of contact loss depending on the on / off processes of the piezoelectric transducer(Di Gironimo et al., 2016; Di Gironimo et al., 2017). They developed a sensor that detects contact loss defects with a sensitivity equal to 82% by means of a two-way classifier. The use of a sole pressure system Amigo (by World Athletics) is currently under trial. The system consists of piezoelectric sole pressure sensors (less than 1 mm thick) that collect contact loss data, which is subsequently transmitted to a control unit by R-FID (radio frequency identification). The insoles system allows direct measurement of contact loss, but from the athlete's point of view it can be invasive and can be said to be uncomfortable enough to affect the outcome of the race. Indeed, direct contact with the foot can lead to problems (e.g. blisters, nail damage), especially for long-distance competitions specific to race walking. The use of wearable inertial systems, even if they do not offer a direct assessment of race walking temporal events, could potentially reduce the discomfort of sole pressure systems and be more user-friendly in real training and competition scenarios. Taborri et al. used a single inertial sensor (with a sampling frequency of 1 Hz) placed on the S100 vertebra to relate acceleration patterns to temporal events of walking for the assessment of contact loss. In an experimental verification study involving seven Australian race walkers, in which more than 80 steps were collected, the accuracy of inertial-based detection of loss-of-contact events was equal to 91% of the values obtained from video analysis (Taborri et al., 2019). Another study presented a method based on machine learning algorithms for the identification of race walking violations (loss of contact and knee bending). They started testing a system of seven inertial sensors (with a sampling frequency of 60 Hz) and included eight elite Italian race walkers in this study. A total of 972 steps (i.e. 1944 steps) were collected from the walkers. Based on the data collected by four different body segments, three different signal combinations for each body segment were elaborated using nine different machine learning algorithms (108 classifications in total). The validation of the classifications was carried out using a coach's judgmental evaluation as a criterion in this study, where they reported that the classification based on a second-order support vector machine fed by shaft linear acceleration gave the best performance with an overall accuracy value equal to 93% according to a subjective evaluation of a coach (Caporaso and Grazioso 2020).

Conclusion

As a result, various protocols and sensors for loss of contact and knee bending violations have been studied for many years in order to make objective evaluations in addition to the monitoring of the walking competition in the Olympics since the 1908 Olympics and the observation of the referees. It can be said that with the use of wearable technology in the race walking branch during the competitions in the future, it can be said that the new era is rapidly approaching in the evaluation of this branch by providing objective and evidence-based refereeing.

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Chapter 5

Technological Development in the Cycling

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Abstract

There is a linear relationship between the cycling branch and technological developments. The development of technology over time and its combination with the sports industry has enabled the data obtained in training and competitions to be obtained instantaneously. Cyclists have started to use lighter and higher quality bicycles in training and competitions with developing technology. With the introduction of pulse and power measurement devices and the development of tests suitable for the cycling branch, the possibility of determining the performance status of athletes and preparing more efficient training programs has been developed. When the competition results and technological developments from the past to the present are analysed, technological developments in the cycling branch positively affect the performance of cyclists.

CONCEPT OF TECHNOLOGY AND INTRODUCTION

When people hear the words technology or technique, they think of a form of machine or hardware. However, the word technology alone does not include mechanical hardware. Technology also encompasses the enterprise dimension. The concept of technology is called a technical language, an applied science, a concept related to techniques, a method in which it is used for the realization of an applied purpose, and the general name given to all the developments made so that people can live more comfortably (İşman, 2001). According to a different definition, it is to express the knowledge and experience necessary for the production of a good or service as a whole (Camkıran, Sersan, & Yıldız, 2021).

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Technology and Sports Industry

With the developing technology, the sports industry has also been positively affected. Many products have been developed through service industry technology and made available to users (Tekin & Karakuş, 2018). With technological advances, technology has an important effect on sporting equipment and sports fields to be more ergometric. Sporting materials influenced by developing technology have been effective in breaking new records for athletes (Atasoy & Kuter, 2005).

Developments in innovation, communication, the internet and technology form the cornerstones of the industry. As in all industries, there have been technical, scientific and technological developments. In this way, the integration of sports and technology has been realized. Through technological developments, data is processed instantaneously in training and competitions (Tekin & Karakuş, 2018). We can transfer our data from training and competitions to cycling monitors or apps using sensors or cloud services via a wired or wireless internet connection. For these devices to communicate with each other, the connection is established via Wi-Fi, NFC, RFID, Bluetooth and Zigbee, while technologies such as GPRS, GSM, LTE, 4G, and 5G are used for local wireless network connections (Banger, 2017). For example, cyclists use heart rate bands and power measuring devices in training and competitions. These devices allow the data obtained in training and competitions to be transferred to bicycle monitors or applications developed for the device via Bluetooth connections.

DEFINITION AND HISTORICAL DEVELOPMENT OF THE BIKE

A bicycle is defined as a non-motorized vehicle in which people transfer their power to the rims via pedals (Aydilek & Sarıçiçek, 2019; Morpa, 1997). The word bicycle comes from the Latin bis [twice] and the Ancient Greek κύκλος [circle] (Wilson & Schmidt, 2020).

The history of the bicycle goes back as far as human history. Although quite different from its present form, the first bicycle was seen in China in the 12th century. But in 1817, German Baron Karl Von Draise invented a two-wheeled bicycle that could move with the thrust of its rider. In 1839, the effective use of pedals was provided by Kirkpatrick Macmillan of Scotland (Aydilek & Sarıçiçek, 2019; Wilson & Schmidt, 2020). In 1868, the bicycle spread from Paris to Belgium, the Netherlands, Germany and the United States (Wilson & Schmidt, 2020). In 1874, H. J. Lawson developed the first chain-driven bicycle. In 1888, J. B. Dunlop saved the bicycle from being

jerky by using hollow tyres and made it comfortable and useful (Aydilek & Sarıçiçek, 2019; Wilson & Schmidt, 2020). The first bicycles in our country were seen in the Ottoman Period in the 1880s (Aydilek & Sarıçiçek, 2019).

The introduction of the bicycle to Turks began in 1885 when an American named Monsieur Tomas Istefanis travelled around Istanbul, Izmit, Ankara, Yozgat and Sivas provinces with his bicycle. In the 19th century, Izmir and Thessaloniki were the most common places in the Ottoman Empire outside the capital Istanbul. During the Ottoman Period, the first bicycle competition was held in Izmir on May 15, 1895 and in Istanbul on August 18, 1895. The first major road race in Turkey in 1924 was held between Fethiye and Antalya. The bicycle has provided mobility in both daily life and sports in the 120 years from the 1890s to the present day (Süme & Özsoy, 2010).

Modern bicycles began to be widely used in the United States in the 1970s. Bicycle sales have increased to exceed automobile sales. Initially, three-speed models were fashionable, but later they were replaced by ten-speed models. With the decline in interest in road cycling in the United States, interest in lighter road bikes has increased. In California, downhill bikes have been introduced. With the sea change event in 1982, there was a transition from road bikes to mountain bikes and from thin tires to thick tires. The interest in mountain bikes was not as short-lived as in road bikes, and cyclists used road bikes for commuting to work, shopping and travelling over rough roads. These bikes have front and rear suspension, carbon, and aluminum frames, hydraulic disc brakes and 27 gears as a gear system (Wilson & Schmidt, 2020). With the developing technology, 12-gear systems have started to be used over time. There has been a shift from mechanical gears to gear systems with electronic and wireless connectivity (Shimano, 2023).

Purposes of Use of the Bicycle

The way the bicycle is used and its role has changed over time. These can be listed as use within the city, use on rough roads and terrains, use for sightseeing purposes between cities and long-distance roads, use in short and long-distance races, for acrobatics and demonstration purposes, for tourism purposes, as a means of fitness and exercise (Aydın, 2015).

While individuals use bicycles in daily life, there is no limitation on the design of their bicycles and the components on them. However, there are restrictions on the type of bicycles of cyclists participating in cycling competitions. These limitations are set by the International Cycling Union

(UCI). The UCI gives details of what the components will be like in a standard bike used to participate in competitions (UCI, 2023).

Development of Technology in Bicycle Components

Various components on the bicycle can affect the performance of cyclists. These components can mainly be explained as rims, cranksets, gear systems, shifters, and tyres.

There are different types of cranksets among bicycle components. Elliptical cranksets, normal cranksets, and single, double and triple cranksets can be given as examples. Elliptical cranksets can be attached to normal cranksets. In this case, the pedal movements of the athletes remain circular, but the speed and gear ratio varies. The purpose of elliptical cranksets is to reduce the time spent in the upper and lower dead spots of the pedal. The ovality degrees of the elliptical crankset is determined by using the ratio of the large diameter of the underlying ellipse to its small diameter. In the 1890s, the prevalence of these cranksets decreased when cyclists using elliptical cranksets, which had an ovality of approximately 1.3, could not achieve the performance they wanted in the races. In 1930, the ovality ratio of 1.1 Thetic cranksets began to become popular. Compared to circular cranksets, there is no deterioration in the performance of cyclists and it has even been shown to improve the performance of some athletes. In the 1980s, Shimano produced the non-elliptical Biopace (Wilson & Schmidt, 2020). Today, different brands offer various crankset preferences for cyclists to use most efficiently (Campagnolo, 2023; Shimano, 2023; Sram, 2023). However, over time, cyclists have started to prefer single-leaf cranksets to make their bikes lighter.

One of the factors affecting the speed of cycling athletes is the hubs of the wheels. Wheel hubs are ball and bearing according to the companies. There are various levels of aluminium and carbon wheels according to the quality of the wheels and the hub condition. (Shimano, 2023; Sram, 2023).

Wheels are one of humanity's greatest inventions. Their ability to carry a load of low resistance depends on their size, the ground condition of the surface being travelled, its hardness, and the characteristics of tires and suspensions. When riders are travelling on unstable ground, the uneven ground shakes the cyclists and delays their acceleration. Thomson in 1845 and Dunlop in 1888 invented pneumatic tires to reduce the effect of the force generated during a collision on their cyclists, to reduce energy losses and to make them more comfortable when moving from one place to another (Wilson & Schmidt, 2020). With the advancement of technology day by

day, different types of tyres have started to be produced with the use of bicycles both in daily life and in competitions. These tyre types range from tubeless tyres to tubular tyres (Vittoria, 2023). Likewise, there has been a transition from aluminium wheels to carbon wheels, and from unprofiled wheels to profiled wheels. In this way, it allows athletes to be less affected by the wind and to go faster (Shimano, 2023).

Another piece of bicycle equipment is the brake. Brake systems vary according to the type of bicycle and the purpose of use. Piston brakes are used in some children's bicycles and tricycles. The disadvantage of this type of brake is poor performance in rainy weather since the tires constantly get wet. The internal expanding drum brake system is a hub brake system similar to the old automotive brake system. It began to be widely used in the 1930s but lost its popularity over time because it was heavy with rim brakes. These braking systems are becoming popular to eliminate the problem of rim and tire overheating. The reverse pedalling system brings multiple discs together when the cranks are turned backwards. This braking system works on oil and is not affected by weather conditions. Coaster brakes break off and don't have a lot of surface area to dissipate heat. During prolonged driving and intensive use situations, the braking systems can reach high temperatures, which adversely affects braking performance (Wilson & Schmidt, 2020. A different type of brake used by cyclists is the disc brake system. This brake system is a preferred form of brake in motorcycles, automobiles, racing cars and aeroplanes. Various types of disc brakes can be used in bicycles according to the budget situation. Brake systems are in the form of a disc partition connected to the hub, brake pads and calliper. These brake systems can work with mechanical wire cables or hydraulics. Compared to other braking systems, and in wet weather conditions, the braking performance is better. There are holes in the discs to reduce their weight and cool them (Shimano, 2023; Sram, 2023; Wilson & Schmidt, 2020). The rim brake system is the most popular type of brake worldwide. This braking system consists of a gear lever, a pad made of rubber material, a calliper and gear wires. The brake pads are very sensitive to water. Electric brakes are only used on some types of e-bikes. In addition to mechanical brakes, they are usually installed on the hubs of the bike. There are different braking options for downhills. When the mechanical brake lever is pressed, medium braking is automatically activated. Magnetic and aerodynamic brakes are used in a variety of stationary exercise brakes. Not suitable for road bikes (Wilson & Schmidt, 2020).

Another factor that affects the performance of cyclists is the helmet. Athletes prefer lighter and aerodynamic helmets in competitions (Wilson & Schmidt, 2020).

The Development of Speed in the Cycling Branch with Developing Technology

Cyclists have started to reach longer distances and speeds with the developing technology. The wheel was invented thousands of years ago and people do not exceed 15 km/h on the bicycle invented by Draisine 200 years ago. This speed is slower than the speed that people reach when running or skating. But soon the bicycle showed a great improvement (Wilson & Schmidt, 2020). With the development of technology, the UCI track cycling records for a fast start over 200 m have reached 77.0 km/h for men and 69.3 km/h for women. A study of the outdoor altitude velodrome achieved speeds of 63.16 km/h in the unique men's category (in 2008) and 54.04 km/h in women (in 2009) (Wilson & Schmidt, 2020).

In the first Olympic Games held in 1896, the road bicycle branch also took part. The first men's athlete in the Olympic Games completed the 87-kilometre course at 3:22:31 at a speed of 25.80 km/h (InternationalOlympicCommittee, 2023; Wikipedia, 2021). The men's branch of road cycling at the Tokyo 2020 Olympic Games was held on a 234-kilometer course. The winning male athlete completed the race in 6:05:26 hours with a speed of 38.43 km/h. In the women's category, she completed the 137.0 km course with an average speed of 3:52:42 hours and 35.32 km/h (Vikipedi, 2023).

In a study conducted by Haake (2009) to determine the effect of technology on four sports branches, it was found that athletes improved their performance by 24% in 108 years in the 100-metre sprint, 86% in 94 years in pole vault, 95% in 76 years in javelin throw, 221% in 111 years in one-hour cycling record and 35% in 32 years in four-kilometre individual pursuit.

Advancement of Technology in Bicycle Measuring Devices

With the development of bicycle ergometers, it has become easier to follow variables such as the mechanical efficiency of cyclists, heart rate, respiratory rate, etc. during measurements (von Döbeln, 1954). Bicycle ergometers have a frame structure, seat, handlebars and cranksets that reflect the normal bicycle appearance. Some ergometers can measure hand power output as well as foot rotation (Lanooy & Bonjer, 1956; von Döbeln, 1954).

Pedalling performance is related to the force exerted by the cyclist and the resulting fatigue. These different power levels range from a few seconds to a few hours for cyclists. To test the pedalling performance, tests performed on the bicycle ergometer in the laboratory environment are advantageous in terms of keeping the resistance constant. However, these tests can be applied

outdoors on a flat road, on slightly hilly ground, against the wind or as sprint studies. Athletes with different levels of power produce power with different characteristics. Sprinter athletes have better short-term power output, while long-distance athletes have better long-term performance values (Wilson & Schmidt, 2020).

Pulse in the Cycling Branch

Monitoring the performance of athletes, and determining and controlling their training intensity is important for competition athletes. That's why heart rate has long been the gold standard in practising and tracking cyclists' workouts (Theobald, 2023).

Depending on the devices used by the cyclists, the pulse rate of the cyclists can be measured using a pulse band worn on the wrist, arm and chest area. While the data from the first heart rate meters are uploaded to the internet via an infrared connection, the data can be easily uploaded to the internet with Bluetooth or ANT+ sensor in the latest developed devices.

Figure 1. Example of USB made for transferring pulse data

Bi-directional infrared data communication is provided via USB (Polar, 2023).

Figure 2. Arm and chest heart rate bands with Bluetooth capability that provide ANT+ data transfer. (Garmin, 2023; Polar, 2023; Wahoo, 2023)

Figure 3. ANT+ sensor that transmits data from smart power meters to the computer (Garmin, 2023).

ANT+ sensors are used to prevent data loss during Bluetooth data transfer.

Polar M340 Garmin Venu 3S

Figure 4. Devices that measure from the wrist (Garmin, 2023; Polar, 2023).

Figure 5. Devices for monitoring heart rate and other data via bicycle monitors

The Use of Power Meters with the Advancement of Technology

Power outputs are one of the best tools for cyclists to control external loads (Gandia Soriano, Carpes, Rodríguez Fernández, & Priego-Quesada, 2020).

Indoor power meters and ergometers first appeared in the late 1880s. Andrew Coggan, an exercise physiologist, began working on ergometers in the physiology laboratory in the early 1980s. Through the use of specific protocols, he learned how the body responds and what changes in blood-

lactate levels occur. With the introduction of suitable mobile meters in the late 1990s, more information began to be obtained during training and competition (Allen & Coggan, 2010).

Power output data can be obtained on the track, on the road, in off-road conditions and various environments including indoor space. Power measuring devices were first introduced to commercial production of the SRM in the 1980s. The SRM power meter was first used by riders such as the East German cycling national team and Greg Lemod, who competed in European competitions. In recent years, power measuring devices have become widespread and the market network has expanded greatly (Yeh vd., 2022). Mobile power meters can be easily used when cycling outdoors or indoors (Passfield, Hopker, Jobson, Friel, & Zabala, 2016; Schneeweiss, Haerlen, Ahrend, Niess, & Krauss, 2018). It is a valid tool for determining the power output of cyclists. The measurements made give information very accurately and reliably. The devices are attached to the bicycle and used to monitor and evaluate the performance of the athletes in training and races through the data obtained.

Mobile power meter devices are produced by different companies. Examples of these companies are Garmin Vectors, Stages Cycling Powermeter, and Cycleops Powertap. These devices can measure in different ways from different zones. For example, it is possible to measure the power output of cyclists from the shoe (Zone DPMX), pedal (Garmin Vector), Hub (Cyclops Powertap), middle hub (Rotor INpower), crankset (Stages Powermeter) (Passfield vd., 2016). For cyclists and professional athletes, it can be used a variety of power-measuring devices on almost every type of bike (Schneeweiss vd., 2018). Modern power measuring devices such as the Schoberer Rad Messtechnik (SRM) and PowerTap, which can be mounted on the bike, give more efficient results (Wilson & Schmidt, 2020). Pedal-based power meters have several advantages. In a study comparing the validity of the pedal-based Favero Assioma Duo (FAD) power meter and the SRM power meter, which is considered the gold standard, the FAD was found to be valid for measuring maximum efforts (Yeh vd., 2022). CyclingPeaks software was developed by Andrew Coggan and Kevin Williams in 2003. In this software, cyclists can load their workouts on the power meter and analyze the workouts they have done. Thus, they were able to follow the data of the cyclists in training and competitions. For this reason, it is the best way to control the intensity of training and competitions (Allen & Coggan, 2010).

Figure 6. Examples of stationary power measuring devices

Constant power measuring devices can be given the feeling of training outdoors by applying inclination or different protocols.

Figure 7. They measure power from the pedal, crankset, and rear hub measure in different ways (Garmin, 2023; PowerTap, 2023; Shimano, 2023; StagesCycling, 2023).

Tests Used in the Bicycle Branch

With the use of power meters, various tests can be carried out to monitor the performance of cyclists:

Critical Power: It is defined as a power output that cyclists can sustain forever. This power output is obtained as a result of the mathematical formula curve adaptation of the test results obtained by short-term tests (Wilson & Schmidt, 2020). Hugh Morton and Hogson (1996) note that tests performed at intervals of 2-15 min to determine the critical power always fit well.

A similar definition is defined as the level of power that the cyclist can sustain for one hour (Wilson & Schmidt, 2020). Allen and Cogan (2010) define the FTP test as the power output that cyclists can sustain in a semi-stable state for one hour. However, the long duration of this period is difficult and stressful for athletes. Therefore, over time, the 20-minute FTP test was introduced. A 45-minute warm-up protocol is recommended for athletes

before starting the test. After 20 minutes of time trial after warming up to obtain the FTP value, the average power output obtained by the athletes is 0.95 (Allen & Coggan, 2010; Mcgrath, Mahony, Fleming, & Donne, 2019; Valenzuela, Morales, Foster, Lucia, & Villa, 2018). In addition, the FTP value of the athlete can be found by calculating 0.90 of the average power output of the cyclists for eight minutes with a different protocol (Allen & Coggan, 2010). According to the FTP value, the training zones of the athlete are determined. In addition, when the FTP value of the cyclist is divided by the body weight, the relative power value is calculated. This value allows us to estimate the number of training hours and training stress score (TSS) that the athlete should do weekly and monthly.

An important test for cycling athletes is the anaerobic power wingate test. The test was first introduced by Ayalon, Inbar and Bar-Or (1974). The test starts with 60 cadence and the athlete is asked to perform the best performance he/she can perform without getting up from the saddle for 30 seconds. During the test, the data are recorded at intervals of five seconds. As a result of the test, average power, maximum power, minimum power, and fatigue index are calculated (Castañeda-Babarro, 2021; Wilson & Schmidt, 2020).

Table 1. Training zones by functional threshold pulse (FTHR) and FTP value

Training Zones	FTHR	FTP
Zone 1	≤81%	≤55%
Zone 2	82%-89%	56%-74%
Zone 3	90%-93%	75%-89%
Zone 4	94%-99%	90%-104%
Zone 5	100%-102%	105%-120%
Zone 6	103%-106%	121%-150%
Zone 7	≥107%	≥150%

Table 2. Volume values that cyclists should make according to their performance status (Friel, 2018)

Category	Annual Recommended Hours	Weekly Average Hours	Annual Recommended TSS	Weekly Average TSS
1 or 2	700-1.000	14-20	35.000-50.000	700-1000
3	500-700	10-14	25.000-35.000	500-700
4	350-500	7-10	17.500-25.000	350-500
5 or Youths	220-350	4-7	11,000-,17,500	200-350
Masters	350-650	7-13	17.500-32.500	350-650

Figure 8. Athletes can follow their training data through various software.

Figure 9. It is ensured that athletes' training and performance status can be followed with various applications.

Athletes can be analyzed by uploading their workouts to various applications such as TrainingPeaks or Interval.uci. In addition, fatigue and fitness can be examined together with the analysis of the trainings (Intervals. icu, 2023; TrainingPeaks, 2023).

CONCLUSION

With the development of technology, bicycle athletes have been provided with more aerodynamic and lightweight bicycle usage opportunities. In addition, with the development and increase in the number of components that cyclists can use every day, more options have been offered. With the production of pulse and power measuring devices and the use of various tests, the performance status of athletes could be determined. In addition,

it has been possible to implement more efficient training programs. When the competition results of the athletes are examined with the technological development to the past and present, it can be said that technological developments have positively affected the performance of the athletes in the cycling branch.

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Chapter 6

Stages of Technological Development in Taekwondo

Nuray Satılmış[1]

Abstract

One of the popular Olympic branches today is taekwondo. Electronic body protection systems (EBP) have undoubtedly contributed greatly to this population growth. The present study aims to review the scientific studies on electronic body protection systems and scoring used in taekwondo. The study is prepared in a compilation format. The journals in Web of Science databases were searched by using the keywords "taekwondo" and "electronic system" and "score" together. While determining the articles, no restrictions such as review, meta-analysis, research article, or year of the research were applied. However, papers were not included in this study. A total of 10 articles that met the specified conditions were analyzed. It can be said that the EBP system increases the transparency in the results of the competitions and the pleasure of watching due to its effects that push the game rules to change.

INTRODUCTION

The sports industry has gradually increased the use of technology to facilitate performance improvements. Technological innovation is on the agenda of most sports organizations because of its impact on performance (Ratten, 2020). It means that science needs innovative forms of technology to further advance society in the 21st century, where human beings have overstepped their boundaries (Ferreira, 2020). For example, it has been claimed that half of the world records in sprint sports to date are the result of changes in technology and the other half are the result of actual sporting performance (de Koning, 2010). It has been reported that technological advances have a significant effect on the performance development of cycling, 100 m sprint, javelin (Haake, 2009), pole vault (Balmer, 2011 & Satılmış,

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2023), long jump, high jump, triple jump (Balmer, 2011), amputee sprint (Dyer, 2015) and swimming (Foster, 2012 & Stefani, 2012). In Taekwondo, it encouraged athletes to throw more techniques to the head area (Jae-Ok. K, 2016). As a result, the pleasure of watching increased with high-scoring competitions.

The changes due to the most radical technological developments used in taekwondo from the past to the present have been in electronic body protector (EBP) systems equipped with sensors. It is this development in technology that has changed the fight profile, from scoring to training. However, it has been noted that there are more dynamic and intense body movements (Janowski, 2021).

This study aims to review the scientific studies on electronic body protection systems and scoring used in taekwondo.

Historical Approach to Taekwondo and Electronic Body Protectors

Taekwondo is a Korean martial art whose origins go back thousands of years. It aims to train and strengthen people physically, mentally and spiritually and over time it has turned into a sport. The World Taekwondo Federation (WT) is an official organization responsible for the enforcement of the rules and regulations of the world championships as well as the Olympic Games. WT was established in 1973 to support the development and practice of taekwondo. Under the leadership of the WT, taekwondo took part as a demonstration sport at the 1988 Seoul and 1992 Barcelona Olympic Games. Since the 2000 Sydney Olympic Games, it has been officially included in the Olympic Games program. Para Taekwondo has become an official sport for the Paralympic Games, starting with the 2020 Tokyo Games. The WT is a member of the International Olympic Committee (IOC) and the International Paralympic Committee (IPC). With more than 200 member countries, the WT is one of the most diverse international sports federations. For this reason, it is the most popular martial art today. From 1973 to 2017, the World Taekwondo Federation was called the WTF. It was branded as World Taekwondo (WT) on June 23, 2017, in order to avoid negative connotations in the digital age, to appeal to young and modern audiences and to be able to interact at the same time (WT, 2023).

Taekwondo matches are held in an area of 16 m^2. Athletes perform dynamic movements, fast change of direction, standing on one leg, jumping, and attacking the opponent's body and head with techniques and defence movements against attacks. It is a combat sport that involves the skilful application of techniques and focuses on foot techniques and dynamic foot

movements (Sing, 2017) It is a martial art that emphasises moral and spiritual values and is performed within certain rules for defence and protection.

The rules of the game in sports are being changed in order to strengthen the relevant sports discipline, increase the performance threshold, attract spectators, be the centre of attention of the media and improve the dynamics of the branch. Changing the rules is a common way to change game conditions. Rules provide a unique, distinctive character to the branch (Eaves, 2008 & Arias, 2011) With technological developments, inevitably, the rules of the game of the branch will also change. As with any sport, the rules and regulations of taekwondo have changed over the years.

Scoring decisions, manipulative behaviour and accusations of favouritism in taekwondo competitions became a major problem in the 1990s and early 2000s. There was a perception that match results were often evaluated subjectively and there was a lack of scoring transparency in general. Another problem during these periods was that it was very boring to watch taekwondo matches as athletes generally adopted a safe, defensive-oriented style of play (Moenig, 2015). In this context, the use of technological equipment in taekwondo has become widespread in order to prevent these problems and to increase the international competitiveness of the branch by taking advantage of the opportunities offered by technological services. As a result, after the year 2000, various rule changes and equipment modifications were gradually implemented. Before 2009, competitions were held by the manual system. In the manual system, the techniques effective on the opponent's safeguard and head area were subjectively evaluated by the referees. Since 2009, the WT electronic system has been implemented in competitions. Thanks to the electronic system evaluations used today, more objective scoring is made.

Development Process of Electronic Body Protective Systems and Their Reflections on the Game Rules

After the 2004 Athens Olympic Games, WT began promoting the inclusion of Electronic Body Protector (EBP) in competitions. EBP was created to protect the athlete's body and to be able to score accurately. Although EBP has been used since 2007, this technology was officially used for the first time at the World Championships (Copenhagen, Denmark) in October 2009 (Del Vecchio, 2011). With the introduction of EBP, major changes were made to the rules of the game. As of this year, the EBP system has been used in different brands and models in order to make accurate scoring and increase the pleasure of watching.

Table 1: Systems used in competitions from the year EBP started to be used until today

Competition Year	Competition Name/Location	EBP System Used
2008	European Taekwondo Championships Rome, Italy	Adidas
2008	Beijing Olympic Games	Manual
2009	World Taekwondo Championships Copenhagen, Denmark	LaJust
2010	European Taekwondo Championships St. Petersburg-Russia	Daedo
2011	World Taekwondo Championships in Gyeongju, South Korea	LaJust
2012	London 2012 Summer Olympics	Daedo
2013	World Taekwondo Championships Puebla- Mexico	Daedo
2014	Manchester World Grand Prix Series (WGPS)	Daedo
2014	European Taekwondo Championships Baku-Azerbaijan	Daedo
2015	World Taekwondo Championships Chelyabinsk-Russia	Daedo
2016	European Taekwondo Championships Montreux-Switzerland	Daedo
2016	Rio Olympic Games	Daedo
2017	World Taekwondo Championships Muju-SouthKorea	KPNP
2018	European Taekwondo Championships Kazan-Russia	Daedo
2019	World Taekwondo Championships Manchester-GreatBritain	Daedo
2020	Tokyo Olympic Games	Daedo
2021	European Taekwondo Championships Sofia-Bulgaria	Daedo
2022	European Taekwondo Championships Manchester, United Kingdom	Daedo
2022	World Taekwondo Championships Guadalajara-Mexico	Daedo
2023	World Taekwondo Championship Baku-Azerbaijan	KPNP

In 2009, the EBP used was the LaJust System. With this system, the most important changes in the rules of the game were that rotating body kicks were awarded 2 points and head kicks were awarded 3 points. To date, the EBP system and game rules have been updated gradually and systematically.

In order to better understand the subject, it is necessary to briefly mention the rules of the game.

Game Rules

Some of the game rules of taekwondo; hitting the opponent after the referee intervenes, punching the head area, punching under the body, and going out of the playing area are illegal. With the rules of the game-changing over time, falling to the ground for whatever reason now requires a penalty. While the playing field was 12x12 m square in the manual system, it became 10x10 m square, 8x8 m square and today 8x8 m octagon with the game rules change. In the manual system, punch and foot techniques to the body were evaluated as 1 (one) point and foot techniques to the head were evaluated as 1 (one) point. However, over time, with the introduction of the EBP system, major changes have been made to the game rules scoring system many times. These are;

- With the introduction of the EBP at the 2009 World Championships and the first official use of the EBP in competition, the WT has announced that the following changes to the rules of play are of major significance for taekwondo. At the same time, the video replay practice was included in the competitions in the same year.
- Punch and foot technique to the body protector 1 (one) point,
- Foot technique performed by turning to the body protector 2 (two) points,
- Foot technique made directly to the head area 3 (three) points,
- As of October 7, 2010, in addition to the above game rules, the foot technique performed by returning to the head area scored 4 (four) points;
- With the game rule change on June 1, 2018
- Punch to the body protector 1 (one) point,
- Foot technique made to the body protector 2 (two) points,
- Foot technique performed by returning to the body protector 4 (four) points,
- Foot technique made directly to the head area 3 (three) points,
- The foot technique performed by returning to the head area was evaluated as 5 (points) points. Today, this is how the score evaluation is done.

Due to the inclusion of the EBP system, hits to the head area bring more points. Scoring in Taekwondo is achieved through effective and accurate

punch and foot techniques on the body protector and effective and accurate foot techniques on the head area. The athlete who scored more points by applying foot and punch techniques to the allowed scoring fields was declared the winner of the match. If there was a tie in the score as a result of the competition, the fourth round was held and the athlete who received the first score in this round was declared the winner. However, from 2022 March onwards, the competitions are in the form of round supremacy with the changed game rules. At the end of each round, the round winner is determined. The athlete who wins two rounds in a row has already won the competition and does not need to make the third round. In case of a tie for the round winners, the third round is held and the winner is determined.

Since the introduction of the EBP system, the WT has made many game rule changes. However, not all game rule changes were mentioned in our study.

Protective Scoring Systems

The first electronic body prototypes were developed by Adidas, LaJust (based in Korea) and Daedo (based in Spain). In 2001, the WT had already started the EBP testing process. In 2005, Adidas and LaJust competed to become the first EBP provider to be officially WT certified. WT then chose the LaJust system in 2006 (Moenig, 2015). ETU strongly supported the Adidas system and used it at the 2008 European Championships in Rome (Moenig, 2015). Although the technically immature LaJust system was not ready for the 2008 Olympic Games, it was used at the World Championships in Copenhagen in 2009 (Moenig, 2015). In 2014, at the Manchester World Grand Prix Series 3, the head protector, which is part of the EBP system, used a sensor for the first time (WT, 2023). Then the electronic head protector was systematically used at the World Taekwondo Championships in 2015 (Chelyabinsk-Russia), at the Rio 2016 and 2020 Tokyo Olympic Games. As of 2019, there are only two companies capable of producing electronic PSS: Daedo and KP&P (WT, 2023).

The Adidas EBP system worked according to power and contact and did not have socks with sensors. It was a weak system as it was scored by the collision of sensors located in the knee or even the body protector. Secondly, the LaJust system was used (Tama, 2017). Sensor socks were included in the LaJust System. However, it was an extremely difficult system to score and had many problems, including cell phone interference. An additional sensor was detected in the sock of a Taiwanese athlete at the Asian Games in 2010. In order to prevent illegal situations, athletes were checked with sensors before entering the competition area (Albey, 2017). According to Albey (2017),

the best electronic scoring system available today is Daedo. Points are scored for all areas of the body protector with sensors. In addition, points are only awarded when correct contact and force are used. The Daedo system has Bluetooth wireless technology, recording 5 hits per second, the immediate reflection of the impact intensity, and a safe transmission network. It also has a password-operated system to prevent interference from spreading over an area of more than 100 m (Del Vecchio, 2011). Thanks to the sensors in the socks and head protector, it is reflected in the score when the body protector is hit at a certain intensity. WT calibrates and implements the required level of impact and sensitivity of the EBP system, taking into account weight category, gender and age groups.

METHOD

The presented study was prepared in review format and the answer to the question "How have Taekwondo technological developments been reflected in the game rules?" was sought. In order to reach the answers to this question, the journals in Web of Science databases were searched by using the keywords "taekwondo" and "electronic system" and "score" together. A comprehensive research was carried out by examining the published full-text articles (in English).

While determining the articles to be used in the study, no restrictions such as review, meta-analysis, research article, or year of the research were applied. However, papers and studies not written in English were not included. As a result, a total of 10 articles that met the specified requirements were examined (Figure 1). Since this study is a review research, it does not require ethics committee approval.

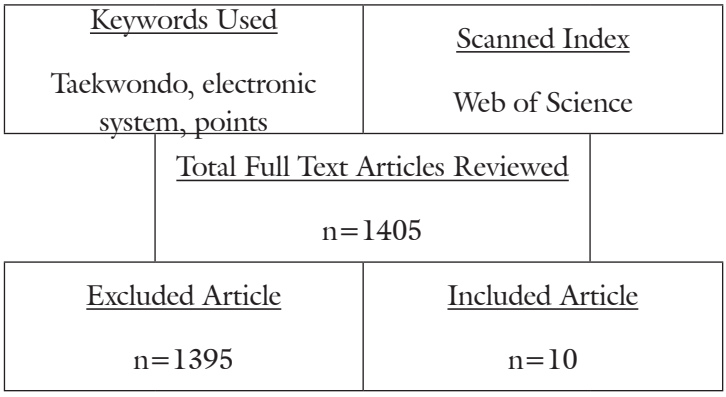

Figure 1: . Study methodology

RESULTS

In the study, 10 articles were examined in which scientific studies on electronic body protective systems and scoring used in taekwondo were investigated. General information about the articles analysed in the studies is given in Table 1.

Table 2: General information of the studies included in the review

Author/year of the study	Purpose	Method	Conclusion
Sledziewski, D., Loniewski, M., Kuder, A., Dias da Silva, R. A., Pedrosa, G. F., Couto, B. P., & Szmuchrowski, L. A. (2015).	The study examines the effects of game rule changes introduced between the Beijing Olympics (2008) and the London Olympics (2012) on athlete and competition profiles.	In the study, the competition records of the Turkish athlete who won the bronze medal in Beijing in 2008, the gold medal in London in 2012 and the Afghan athlete who won the bronze medal in both Olympic Games were examined.	As a result of the study, it was stated that the technical profile used between the Beijing Olympics (2008) and the London Olympics (2012) changed. It was found that the changed game rules increased the use of the front leg compared to the back leg and increased the number of head movements.
Păunescu, C., Piţigoi, G., & Păunescu, M. (2014).	It is based on a systematic analysis of studies published in various databases on injuries occurring during taekwondo competitions and an interpretative study with video analysis detection.	During the 2012 World Junior Championships in Egypt, a total of 732 matches were analysed, including 413 (56%) men's competitions and 319 (44%) women's competitions.	It was concluded that the reduction in the number of head injuries was due to the refereeing system and that strong hits were not necessary to earn points.
Tornello, F., Capranica, L., Minganti, C., Chiodo, S., Condello, G., & Tessitore, A. (2014).	It is the study of the technical and tactical profiles of the junior taekwondo competitions played according to the current game rules.	Technical analyses of the final and final competitions (n = 50) of the Italian Taekwondo Stars championship were performed. Video analytics software program (Dartfish Software Connect Plus 6.0; Dartfish, Fribourg, Switzerland) were used to analyze the records frame by frame (interval = 0.016 seconds).	As a result of the research, it was concluded that the athletes in the star category (a) were more prone to perform offensive actions rather than defensive actions; (b) scored mainly with single-point techniques; and (c) used the back leg more frequently. Specifically, they noted that winning athletes played less offense and more defense than non-winners.

Chong, R. W. L., & Razman, R. (2017)	The reliability of a device designed to test electronic body protectors has been studied.	The mechanical pendulum consists of metal plates and tubular mild steel profiles to simulate a kick striking the electronic body protector.	Data from the study show that the custom-made apparatus is reliable. Therefore, it was concluded that the device could be used to measure the reliability and accuracy of the taekwondo electronic body protector scoring system.
Rahmansyah, M. R., Anita, W., Istiqomah, L., Setiawan, Y. B., Juniardi, Y., Rifqi, A., & Septiani, R. (2019)	To design a wifi-based score calculation system.	A six-button Wi-Fi device consisting of three buttons for blue athletes and three buttons for red athletes was used. If the scores of each referee are the same as the value given by at least two of the three referees, the final score was given by the operator and Wi-Fi was used for data synchronization.	It was concluded that the Wi-Fi-based score calculation system seamlessly receives data from a distance of 45 m, making it easier for referees to perform their duties without the need for a LAN cable and speeding up system installation.
Choi, C. H., Oh, H., & Jeon, M. (2021)	The adequacy of the body protector and scoring system was examined.	It consisted of data from 188 matches at the 2018 Asian Games, taken from the official website of the Asian Taekwondo Federation.	It was found that the technical score effect standard set by WT of the Protective and Scoring System approved by the World Taekwondo Federation was high in all weight classes except the 58 kg weight class.
Apollaro, G., & Falcó, C (2021)	This study aimed to investigate the relationship between the colours of electronic body and head protectors and success in matches in which electronic body and head protectors were used.	1.327 competitions were recorded on DVD.	It was determined that there was no statistically significant relationship between the result of the match and the color of the winner's protectors.
Qureshi, F., &. Krishnan, S. (2022)	To analyze legal and illegal head techniques in electronic head protectors and to design head protectors.	Robustness, sensor placement and shock classification tests have been performed.	In the robustness test, it was found that both the accelerometer and the gyroscope can linearly detect impacts. It was determined that placing the sensor in the back of the head was ideal. Impacts are categorised as legal and illegal.

Apollaro, G., Moreira, P. V. S., Rodríguez, Y. Q., Morales-Sanchez, V., & Falco, C. (2022)	This study aims to investigate the relationship between the colour of electronic protectors and the result of the competition in national taekwondo competitions.	Data for 1155 competitions in 2019-2021 Italian and Uzbekistan Senior Championships from publicly available online sources (https://www.tpss.eu/ login.asp (accessed November 28, 2021) and https://www.ma-regonline.com/ (accessed December 15, 2021)	It was concluded that the electronic system body and head protector in national taekwondo competitions is a fair system and does not affect the winner and loser in the outcome of the match.
Huang, T. Y., Tang, W. T., Liu, T. T., Hamill, J., & Hu, C. (2022).	To investigate the biomechanical differences between rotating techniques with higher and lower impact magnitude using electronic body protectors.	Eighteen elite-level university Taekwondo athletes participated in the study. The Daedo system was used in the research and eight Eagle digital infrared high-speed cameras (Motion Analysis Corporation, Santa Rosa, CA) were installed to surround the athlete for the rotating technical analysis.	As a result, it has been found that elite athletes can achieve a high-impact EBP index by increasing the linear speed proximal to the thigh and leg even at the same foot speed level. To establish a valid score, post-impact leg momentum as well as the pre-impact velocity of the proximal part of the leg was found to be a key performance indicator.

CONCLUSION

Although the development of EBP systems, which developed gradually, dates back to the 1990s, it was first introduced in 2008. It can be said that LaJust prioritizes the EBP system. Initially, the system consisted only of an automatic, electronically scored body protector. This was an incomplete and hybrid structure. Due to several failures, it was not continued. The Daedo system is believed to have been a success at the 2012 London Olympic Games and contributed significantly to the inclusion of taekwondo in the next two Olympic Games. On the other hand, it has shown a performance that shows that it will maintain its place in the EBP for a long time. It was also concluded that the EBP system increased the pleasure of watching the effects of the competition results that pushed transparency and game rules change.

The format of the score evaluation of the punch technique to the body has not changed since the manual system. In the Daedo system used today, the punch technique is evaluated by the referees. The Daedo system currently in use is in gen2 form. WT is trying to develop the gen3 form of this system and is trying to place sensors in gloves to enable electronic evaluation of the punch technique in the future.

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Chapter 7

Technological Advances in Football

Gökmen Kılınçarslan[1]

Abstract

In this section, the technologies recently used in football are analysed. Football is seen as the most popular branch of the world in terms of spectatorship. Technology is used at the highest level in order to improve the performance in football and not to decrease the interest of the audience. Technology is used from the structure of the stadiums to the clothes worn by the athletes. Wearable technologies have made it easy for coaches to provide feedback by providing information about instant performance monitoring of athletes. In this section, a literature review has been made about the technologies used in football. The proposition "Football, which has become a giant industry since the beginning of the 21st century, is obliged to use technology in order to maintain its economic value" has been tried to be explained.

1. Introduction

Starting from ancient times and continuing with the establishment of modern football, football continues to be a sports branch that continues to maintain its popularity without losing its popularity until today due to the fact that it is played, followed and loved by all age groups as well as its interest, excitement, cooperation, competition, socio-cultural, communication and economic value of people and societies.

The popularization of football due to the fact that it is watched and dealt with by a large mass of people coincides with industrialization and its aftermath (Şentürk, 2007). Depending on industrialization and post-industrial transformations, football has become the most talked about sport among other sports branches and its fans are constantly increasing (Kıvanç, 2001). Today, based on the interest in football and the astronomical figures spent on it, it can be stated that the interest in football is constantly increasing

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with the technological, sociological, economic and cultural developments that go one step forward with each passing moment and that it has taken its place in the group of professions as a rent. Known as the branch with the highest popularity, soccer has become a situation that is equated with sports in the minds. So much so that football constitutes one out of every three academic studies in the field of sports sciences. The issue of football popularity, which is open to evaluation from many angles, needs to be looked at from different angles (Öntürk et al., 2019).

Technology and Football

With the advancing technological developments, human life is equipped with electronic devices. Depending on these developments, individuals can easily follow whatever they are interested in through social media, internet websites, blog sites and web media. Football is a popular sport that has been followed, watched and played by millions of people for many years. In some countries, it is not seen as a sport but as a separate reality and a completely different world (Solmaz & Baritci, 2019).

As digitalization resulting from developments in communication and information technologies has transformed people's habits, football has taken its share of this transformation. The fact that this interest continues to increase day by day has caused the game to take on a commercial structure and has turned football into a giant industry. This giant industry, which has actors such as football clubs, media, fans, referees, coaches and players, has undergone a significant transformation with the digital age, which we encounter in every aspect of daily life and changes all habits of humanity. Of course, it is inevitable that this period, which eliminates the distinction between time and space and in which digitalization is intertwined with human life, has manifested itself in a field like football, which attracts millions of people and earns millions. This transformation in football has taken place within many different parameters of the digital age. Technological developments have enabled football to be played on more favorable fields, with better-equipped equipment and presented to the masses through better quality broadcasts (Çırak, 2020).

Technology has historically always found a place in football in one way or another. Shoes, soccer balls, jerseys, stadiums, training techniques, soccer broadcasting and almost everything related to soccer has been changing and developing with technology. These changes have become somewhat visible in recent years with the active use of football statistics and new training techniques in football. Today, one of the biggest factors in the success of

many coaches is recognized as the presence of technological support teams behind them (Çobanoğulları, 2020).

Various laboratories have been established and R&D studies are carried out to create products with sports technology. These technologies, which are not limited to sports products, have shown their effects on many irons such as flags, whistles, headphones used by referees who are the decision makers in sports. Wi-fi, satellite broadcasts, fiber systems used in sports competitions are also examples. In addition, sports facilities have been transformed into smart facilities and turned into new camera systems, scoreboards, computer-aided facilities. With the technological tools and equipment used in training science, future athletes have started to be created in laboratories and analyzes have started to be made in virtual environment (Devecioğlu & Altungül, 2011).

Technology has completely changed the way soccer is played and experienced. With multiple HD cameras allowing us to see every move from every conceivable angle, we now know almost everything that happens on the pitch. For example, we can see which part of the pitch a player spends most of his time on, how many passes he makes, where he makes them and to whom. Technology allows spectators to experience soccer on a whole new level. New technologies on the pitch will make games more enjoyable, especially when they enable the right decisions to be made, which in turn will lead to fewer interruptions and less frustration (Vanhooijdonk, 2021).

With the continued development of microtechnology, player tracking has become one of the most important components of game monitoring in team sports. The 3 main goals of player tracking are; better understanding of training, optimization of training load models at the team level, helping players to decide on their training programs to improve athlete performance and prevent potential injuries (Akenhead & Nassis, 2016).

Football is one of the most followed sports branches in the world, and this interest allows football to be constantly developed and renewed. For this reason, especially the athletes, technical team and all other stakeholders in the football sector want the matches to be managed fairly and impartially. Nowadays, due to technological developments, the development of digital media technology in the field of sports and sporting competitions is a normal situation. Since referees have the potential to change the final result, their chances of making the right decision during the competition have increased by utilizing technological developments (Caz et al. 2021).

The transformation of football into an industrial business has necessitated the transformation of green fields, which are seen as investment areas, into

a fair and transparent area by removing errors as much as possible. In order to ensure a standardized management approach, the use of technology in football has become increasingly important in recent years. The most striking example of this is the Video Assistant Referee System (Engin & Çelik, 2019).

The most important criterion for the future of football is to decide how much technology should be included in football and how much it should be included. Since it does not seem possible to try to ignore mistakes and bear the consequences in industrial football where billions of dollars are spent, technology has been allowed to enter football. In this context; developed countries in football have switched to VAR technology with the belief that technology will encourage players to behave in a more disciplined manner and bring more justice to matches (Orta, 2020).

Hawkeye system works with 7 cameras for each goal. This system combines images from different angles to track the ball in 3D. If the software of this technology decides that the ball has crossed the line, the watch on the referee's wrist notifies the goal with vibration and image alerts. With this technological development, the question "did the ball cross the line?", which is one of the biggest debates in football, is answered (Demir, 2017).

Recently, football has become a field where millions of dollars are spent on issues such as player buying and selling, the renovation and construction of infrastructure facilities, stadiums, uniforms, team name sponsorships, and this industry is growing day by day. In this huge field, mistakes need to be minimized as each sector tries to get its own piece of the pie. In order to minimize errors, we need to take advantage of the opportunities that technology offers us. Therefore, training scientists should produce information for athletes by using technology at a good level and improve their systems by analyzing the information they produce (Sajadi & Rahmani, 2007).

Competition analysis and performance evaluation in football is extremely important for coaches, analysts and teams. Analysis provides useful information for coaches in evaluating the competitions they have played and will play. In the light of this information, it enables both player and team performance to be monitored, minimizing mistakes and increasing strengths (Hughes & Franks, 2004).

Competition analysis in soccer is an important tool that helps teams to evaluate their performance, improve their tactics and gain superiority over their opponents. The performance of soccer players, who are the main

protagonists of the game, indirectly affects the success of coaches. Coaches need objective data in addition to their subjective comments when evaluating their athletes. At this point, competition analysis comes into play, allowing teams to examine their games in a deeper way. It reveals not only the team performance but also the individual performances of the players. Today, soccer now examines even very fine details. The technical teams of the teams reach up to 15 people (Yavuz et al., 2023).

Nowadays, investments in analysis programs are quite large and limited in terms of data transfer. In addition to this information, different analysis programs also provide information about parameters such as passing, shooting, intermediate numbers, number and rates of winning duels (Bal, 2011). In line with the information obtained with the data provided by these systems, coaches can get to know their team and opponents better, observe them objectively and organize the training program (Tokul, 2017). Competition analysis systems, which provide objective information about the team and players, can provide comparative positive and negative data not only daily or weekly but also throughout the season (Araslı, 2010).

Recently, with the development of technology, the methods of analysis in football have moved away from subjective interpretations to objective interpretations. In this way, the system has become more valid and reliable. Interpretation of seasonal data allows us to follow team and individual developments. This data changes every year as the identity of the players changes. Even in player sales, this data has started to be presented to rival teams (Ocakbaşı, 2018).

Professional soccer is a global spectator sport and its players have always been in the public eye. Today, however, new digital technologies, from devices that can track every movement and switch to artificial intelligence tools that can predict a player's behavior, have exposed athletes to more scrutiny than ever before (Ronco, 2022).

Player health monitoring and performance tracking have changed significantly in recent years. Smart clothing technologies are used in player monitoring systems. The use of wearable electronic measurement devices was approved by FIFA in 2015 (Dunn et al., 2018). Smart clothing products such as gloves, socks, swimsuits, shorts, T-shirts, pants, leggings and bras are typically made of advanced textiles that contain interwoven circuits, sensors and additional hardware. Smart clothing and wearables connect to smartphone apps or laptops via bluetooth or wi-fi. Depending on its purpose, smart clothing and wearables can collect all kinds of data such as running speed, muscle activity, breathing rate, heart rate, perspiration

and temperature, step counting, calories consumed, altitude. Distance tracking, step count, anaerobic threshold, fitness and stress levels and many other measurements. Wearable technologies provide objective data that helps maximize training, monitor player performance, determine fitness levels and reduce injury risks in soccer. Coaches, trainers and medical staff analyze and use the data collected from these devices to make data-driven choices, improve player development and enhance performance on the field (Vanhooijdonk, 2021).

Considering the importance of success in sports, the desire of athletes and sports supporters for development is as valuable and high as success. For this reason, investment in nanotechnology in sports is extremely high. Competition and the desire to succeed have driven athletes and teams to this development. Sports equipment produced with nanotechnology is an important factor for athletes and teams to gain advantage. For example, products produced with nanotechnology are used in tennis, swimming, golf, cycling, athletics, winter sports such as ice skating, skiing, sledding, bowling, hockey, baseball, badminton, motor sports, speed sports, sailing, racing boats and football (Şentürk & Özer, 2022).

Another technological development is the leggings used by athletes. The "Smart Legging" leggings prepared by AiQ Smart Clothing, supported by Qualcomm, can measure posture and position with a total of 5 sensors located in the center of the knees, ankles and spine of the clothing. The technology that collects data on pulse and respiration can send the data to the phone via bluetooth. In this way, body analysis of football players can be done more easily (Şentürk & Özer, 2022).

Technological developments have also occurred for the soccer ball, one of the basic tools of football. Adidas has developed balls called "Beau Jeu", which means "beautiful game", developed with the latest technology and provides more grip (Demir, 2017).

Technologies Used in Football

When technological developments in football are examined; it is seen in the literature reviews that it has made significant progress especially in areas such as training and performance analysis, athlete performance monitoring and tracking, athlete health monitoring and tracking, athlete training (talent, technique, etc.), wearable technologies and stadium and field technologies. In this context, the technologies used in football will be mentioned in the light of the reviewed literatures.

- **Kinexon ONE Athlete Monitoring System**

Kinexon ONE Athlete Monitoring System analyzes and measures football players and team performance, tactics, games and training, and provides the right training exercises to achieve specific goals. It includes a variety of exercises developed and recommended by leading sports scientists, coaches and sports associations to ensure that players reach their full potential (Çelebi, 2017).

Figure 1: Kinexon ONE Athlete Monitoring System (Çelebi, 2017).

- **Sentio Sports Analytics Sistem**

Sentio is a cloud-based software platform that collects and organizes data invisible to the naked eye in real time on sports fields, develops predictive analyses about the game based on this data, and presents these outputs to coaches and fans in real time in web, mobile application, television and printed report formats. Sentio processes data from optical sensors during matches, and from chips developed by Eksa Teknoloji during friendly matches and training sessions where athletes are allowed to be implanted with chips, in real time, and extracts the distances traveled by athletes, the locations and duration of their high intensity runs, the difficulty levels of their passes, shots and crosses, and their success rates to support coaches' decisions such as tactics and substitutions during the match. Sentio also allows coaches to instantly revisit desired positions, analyze team placement, inter-block

distances, team width and height, and shape training programs. With Sentio, which removes the human factor in data collection and analysis, coaches' valuable time can be redirected from routine tasks such as data collection to high value-added tasks such as making sense of data and winning matches or tournaments. In Turkey, the system is used in Super League and Turkish National Football Team's home matches (TUBITAK, 2013).

Figure 2. Sentio Sports Analytics Sistem (https://sentiosports.com/2023).

- **TRACAB Gen5 Optical Monitoring System**

The TRACAB Optical Tracking System developed by ChyronHego is an optical tracking system approved by FIFA and achieves high performance under the EPTS program. All the physical, positional and tactical data collected allows for a wide range of applications to enhance fan engagement and the use of a brand new data analysis platform provided by SciSports. This wealth of data provides coaches, managers and image analysts with a single platform and interface for monitoring and analysis. Thus, they can more effectively evaluate their own team's performance to compare with other teams and identify areas for tactical improvement (Linke et al. 2020).

ChyronHego also provides football teams with the Coach Paint image analysis and presentation tool, which has become standard in most of world football. This powerful software allows high-quality graphics to be overlaid on match footage very quickly, helping the soccer technical team to more easily explain the key elements of a match in a visual way. The whole team

and each individual player can thus learn more effectively and improve their tactical awareness and skills (www.sportsvideo.org/2020).

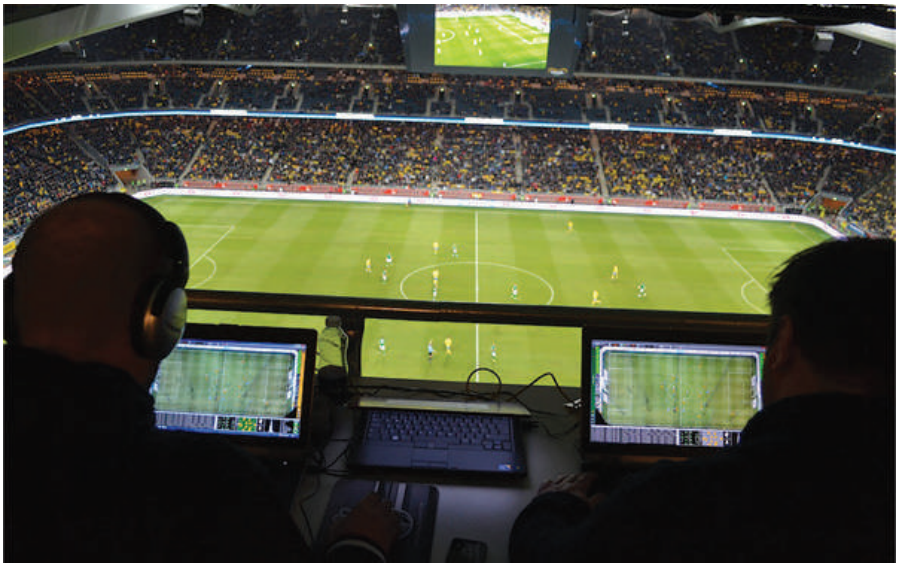


Figure 3. TRACAB Optical Monitoring System (www.digitalmediaworld.tv /2017).

- **Video Assistant Referee (VAR) System**

This system will be used in controversial situations as a joint decision made by IFAB and FIFA to determine whether a goal, penalty, red card, or incorrect player punishment has been given. The "Video Assistant Referee (VAR)" system was developed to assist referees in football matches and has been subject to trials approved by the International Football Association Board (IFAB) responsible for regulating football game rules and sanctioned by FIFA. If the referee requests assistance for a decision, the system will intervene and investigate the incident in question via video footage. This information will then be communicated to the referee through a communication set, and the referee will make a decision based on the conveyed information (IFAB, 2023; FIFA, 2023).

Figure 4. Video Assistant Referee (VAR) System (IFAB, 2023).

- **Semi-Automatic Offside Technology (SAOT)**

Semi-Automatic Offside Technology (SAOT) is a support tool that helps video match officials and pitch officials make faster, more repeatable, and more accurate offside decisions.

While VAR uses video replay technology to deal with various aspects of decision-making in football, semi-automatic offside technology is specialized only in one area. Two technologies work together to enhance consistency when making offside decisions. The new technology consists of 12 specialised tracking cameras mounted beneath the roof of the stadium, which calculate the exact position of each player on the field 50 times per second using up to 29 data points. These 29 data points encompass all limbs and extremities relevant to making offside calls (FIFA, 2023). Semi-automatic offside technology (SAOT) is the latest technological development in football. Since VAR has been implemented at the professional level across the sport since 2018, SAOT has been developed to further enhance the accuracy of refereeing decisions. Rather than reviewing video footage, SAOT uses tracking data to calculate offsides. When technology identifies an offside violation, an automatic warning is sent to the video operations unit, which the VAR team can use to check the validity of the offside line while the game is still in progress. After the VAR team manually verifies the offside lines and determines whether the offside player has intervened in the game, they inform the on-field referee of their decision, and the match proceeds accordingly. SAOT also utilizes a specially designed ball to aid in offside detection. VAR officials track the ball's location and contact 500 times per second by placing a motion sensor inside a specially designed ball. The technology helps identify potential offsides.

Figure 5. Semi-automatic offside technology (Tripathi, (2022).

- **Goal Line Technologies**

Goal-line technology is a technical tool that instantly determines whether the entire ball has crossed the goal line. Goal-line technology has been indispensable in the football world since 2014, when it was first introduced. The technology clearly indicates whether the ball has completely crossed the line. This information helps the referee to make a final decision. The information is transmitted within a split second, allowing the referee to respond instantly. The technology is based on the principles of the magnetic field, which has a sensor inside that sends data to the main server after measuring the magnetic field deviations in case a ball crosses the goal line. Within a very short time the signal is transmitted to the referee's clock and then the referee declares the goal. The main purpose of goal-line technology is to provide more accurate information, i.e. to determine whether the ball has completely crossed the goal line. The system utilises 14 high-speed cameras mounted on the podium/under the roof of the stadium. The data from the cameras is used to create a 3D animation to visualise the decision to fans on television and on a giant screen inside the stadium (FIFA, 2022; https://sportsmatik.com/2021). Four systems (GoalControl, GoalRef, Hawk-Eye and Cairos) have been approved by the International Football Association Board (IFAB) for use in the professional game (IFAB, 2023).

➢ **Goal Control-4D System**

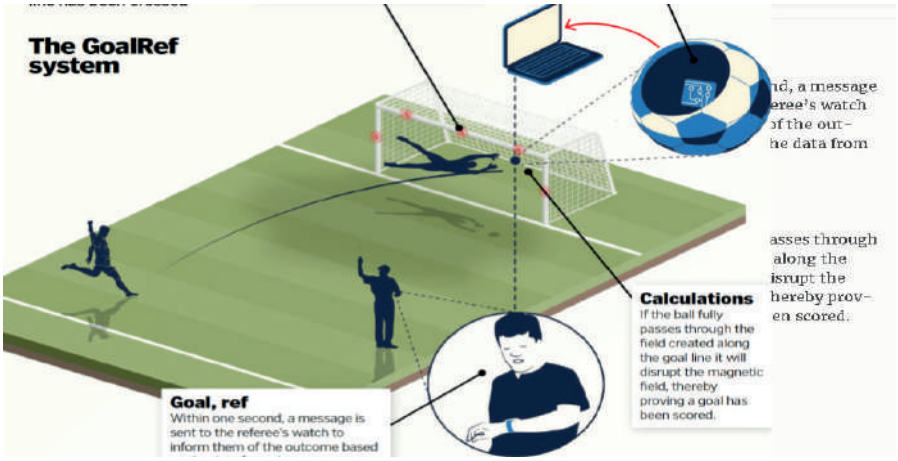
The Goal Control-4D goal-line technology system works with 14 high-speed cameras (7 per goal) installed in the stadium and around the pitch. The cameras track the movements of the players and the ball with a powerful image processor. The system, which distinguishes between players, referees and other objects, places the three-dimensional positions of everything on

the pitch in the coordinate system of the pitch with an accuracy of a few millimetres; when the ball crosses the goal line, it sends a vibration and optical signal to the smartwatches of the officials. Thus, all images of the goal can be replayed (Çelebi, 2017).

Figure 6: Goal Control-4D (Invasion, 2014).

- **GoalRef**

The GoalRef target detection system was developed by Fraunhofer IIS. It is a radio-based system that uses low-frequency magnetic fields to determine whether the entire ball has crossed the goal line. There are two magnetic fields. One is generated in the goal area (using coils attached to the goal), the other in and around the ball (using a passive electronic circuit embedded in the ball). The working principle is basically based on an electronic circuit embedded in the ball and a low-frequency magnetic field around the goal. The data is processed and then wirelessly transmitted to the referee's wristwatch and a message is displayed in real time in addition to a vibrating warning (Wood, 2023; Özeren, 2022).



Resim 7: GoalRef System (www.pressreader.com/2018).

- **Hawk-Eye**

Hawk-Eye is a computer vision system used to visually track the trajectory of the ball and display its statistically most probable profile in numerous sports such as football, cricket, tennis, badminton, rugby and volleyball. The Hawk-Eye system, owned by Sony, was developed by Paul Hawkins in the United Kingdom. The Hawke-Eye system uses three cameras focussed on each goal line, each shooting at 600 frames per second. Hawk-Eye can make an accurate judgement as to whether the ball has completely crossed the line or not, and transmit this information to the centre referee in the form of an audible beep within half a second (Wood, 2023; Özeren, 2022).

Figure 8. Hawk-Eye System (YouTube, 2012).

- **aiScout Artificial Intelligence Programme**

aiScout, an artificial intelligence programme, is a mobile technology platform for football clubs and scouts to generate reliable, comparative data that can assist in amateur talent identification, talent analysis and development. The programme analyses the physical, technical, psychometric and cognitive performance of young athletes during specific drills in exercise and training and allows the athlete to upload their own images. Thus, this mobile application ensures that talented amateur players are seen by professional teams from all over the world and have a higher chance of being discovered (https://ai.io/2023).

Figure 9. aiScout Artificial Intelligence Programme (https://ai.io/2023).

- **Zone7 Artificial Intelligence Programme**

To keep athletes healthy and performing at a high level, the Zone7 programme determines daily injury risk predictions from an artificial intelligence engine and transfers the data to mobile devices. The system inputs data from medical profiles, fitness assessments and wearable devices to determine which players may be at risk of injury. The system provides green, yellow and red indicators for players' daily risk levels, allowing coaches to decide whether to reduce the intensity of a particular player's training sessions to minimise injury risk (https://zone7.ai/2023).

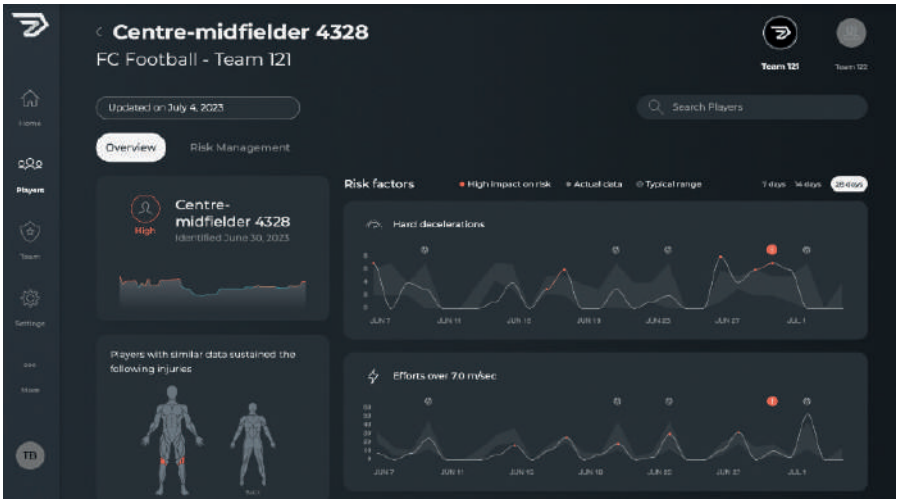


Figure 10. Zone7 Artificial Intelligence Programme (https://zone7.ai/2023).

- **Playertek Pod**

The Playertek Pod consists of a wearable GPS tracker and sensor package that is paired with a compatible smartphone via a dedicated app. The Playertek Pod device is used by attaching it to vests specially designed by Catapult Sports, an Australian company. The Playertek platform utilises a variety of different sensor techniques to track every possible variable during both game performance and training to create a comprehensive high-level picture of the way a player moves, how far they cover, their top speed, average sprint distance and total number of sprints. It is based on the Playertek Pod, which houses all the necessary sensors and technology fitted to the Playertek vest. The pod is extremely small and lightweight, able to withstand the rigours of a professional game while remaining robust and robust. All data collected by the Playertek Pod can be viewed and interpreted in the Playertek app, which is provided free of charge with the earth Playertek platform (Scavuzzo, 2016). If players want to analyse their own game, they can use the Playertek Pod to get basic information such as who ran how much, how many correct passes, how many incorrect passes, as well as advanced data such as heat maps showing the weight of the game. A GPS device is built into this velcro garment, which looks like a small tank top worn over the upper body. After wearing the Playertek Pod and completing your match, it is necessary to pair the device. After pairing, the data is displayed on the screen. In addition to the web application, there are also mobile applications compatible with Android and iOS devices (Çelebi, 2017).

Figure 11. Playertek Pod (Scavuzzo, 2016).

- **Viper Pod Athlete Monitoring Device**

The Viper Pod is a performance monitoring tool used by some of the best teams in the world in many sports such as the Premier League, NFL or NBA. The vest and the viper pod for the pod were developed by STATSports, an Irish company. All relevant metrics including running distance, pace, acceleration or heart rate are monitored by this device. The Viper pod transfers all data in real time using the Viper Live Streaming software and makes all collected data downloadable after each session. There is also the option to see the location and movement in real time from a bird's eye view (Ostsieker, 2016). Another difference of Viper Pod is that it can track collisions and score the instantaneous fatigue of footballers. This makes it easier to make the right decision for substitution, as well as to understand who the fittest players are in the long run (Çelebi, 2017). The device helps to collect large amounts of data such as running speed, stress load, distance travelled, which can be easily displayed. It helps to provide important information to coaches so that they can evaluate the performance of each player. Viper Pod helps to provide a detailed analysis of a player from one session to another in real time. The device can be conveniently worn on the player's body with the help of a belt (https://sportsmatik.com/2022).

Figure 12. Viper Pod (https://sportsmatik.com/2022).

- **Apex Tracking Athlete Monitoring Device**

It is a wearable athlete tracking device developed by STATSports. Apex tracking is a black compression vest worn under the regular jersey. The vest has a tracking device built into a pouch between the shoulder blades that contains a number of sensors. These include GPS to track position, accelerometers to measure speed, gyroscopes to measure direction in three dimensions and magnetometers to record direction of travel The device also contains an embedded processor that synthesises raw data and calculates performance metrics such as distance travelled and number of sprints completed in real time (https://statsports.com/2023).

Figure 13. Apex Tracking (https://statsports.com/2023).

- **f50 Adizero miCoac Crampon**

"miCoach compatible adizero f50" is produced by Adidas Company for football players. It has a speed sensor and performance tracking system (Speed_Cell chip) placed on the sole of the boot. In addition to capturing the movements at a 360-degree angle, the system is able to measure the main performance values, including average speed recorded every second, maximum speed recorded every 5 seconds, number of slaloms and sprint time, distance, short stride and long stride. In addition, the built-in memory can store all of the user's measurements for seven hours. This data can then be easily transferred wirelessly to iPhone, PC and MAC. Players have the chance to compare their performance data with each other and increase intra-team competition (https://hypebeast.com/2012).

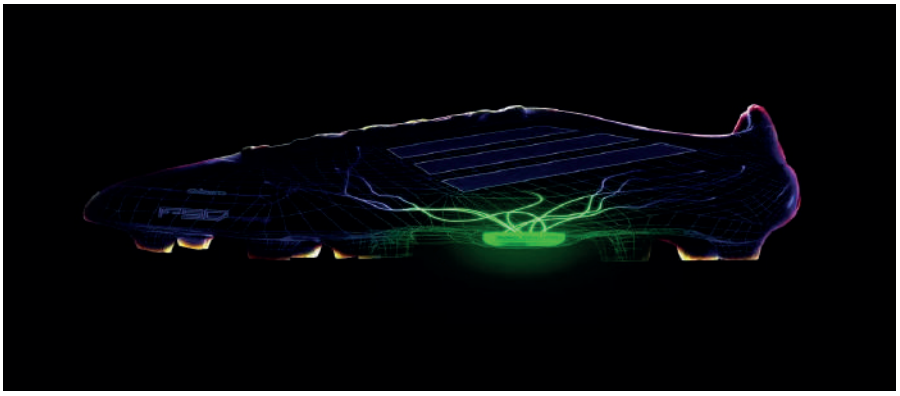


Figure 14: Adidas f50 Adizero miCoac Crampon (https://newatlas.com/2023).

- **Adidas GMR (Shoe Insoles with Chip)**

Adidas GMR technology is a wearable technology developed by adidas in collaboration with EA Sports FIFA Mobile and Jacquard and Google. The Jacquard Chip, developed by Google, is a sophisticated piece of hardware that houses tiny sensors. The data from these sensors is read by Jacquard's advanced machine learning algorithms to identify football movements and wirelessly transmit them to the GMR mobile app. To use the Adidas GMR, it is enough to put the insoles inside the boots or trainers and install the GMR App on a smartphone, tablet, etc. GMR is a smart insole application system that automatically measures data on different types of kicks such as running distance, dribbling, passing and penalty. Thanks to the GMR App application, your football performance can be followed in detail. In addition, GMR not only allows you to track the football matches or sports activities

you physically play, but also transfers your experience to the virtual world by transferring it to the FIFA Mobile version (Vanhooijdonk, 2021).

Figure 15: Adidas GMR (Shoe Insoles with Chip) (Akbaş, 2020).

- **SOCKIT Foot Technique Development Device**

Sockit is a device that helps young footballers (5-12 years old) to improve their technique. It is manufactured by the Californian company Sockit. The working principle is that if you touch the ball when passing or shooting, it gives direct feedback on whether the ball is hit with the correct surface of the foot. The one-size-fits-all wearable device is designed to be securely attached to football shoes. The tracking takes place in different positions, such as on the laces or on the sides, in order to record as many passing and shooting techniques as possible for training. The SOCKIT is made of industrial-strength thermal plastic rubber and is designed to withstand shock, impact and other extreme conditions. It includes a light-emitting function supported by 6 LEDs powered by a replaceable lithium battery and is one size fits all (Ostsieker, 2016).

Figure 16. SOCKIT (https://socalfieldtrips.com/2023).

- **miCoach Smart Ball Technology**

Smart ball technology, FIFA event miCoach, developed jointly by German Cairos Technologies and Adidas companies, is a bluetooth and application compatible football ball with sensors inside that can detect speed, rotation, kick hardness and flight path. The data from these can be simultaneously transferred to the application on the smartphone. The miCoach smart ball's application contains information on the intensity of the shot, the trajectory of the ball's flight and return, as well as the impact points. The miCoach app offers training programmes for players to improve their hitting skills and reach advanced hitting techniques such as the "knuckle ball" shot. In the "Challenge yourself" section, there are goals such as hitting the ball at a certain speed, curling around the wall or hitting a professional level standing ball. In addition, with the "record book" section, all strokes are recorded and progress can be monitored (Demir, 2020; Çelebi, 2017).

Figure 17. miCoach Smart Ball (www.jebiga.com/2023).

- **Grass Field Technology**

Undoubtedly, football pitches have also received their share from the technological developments in football. Today, technological investments are made in order to make football pitches healthy, convenient, equipped and better quality football for players. Natural grass and artificial turf are used in football pitches. Especially natural grass pitches are the most preferred pitches of professional football teams. However, the maintenance and protection of these fields for four seasons is very difficult and costly. Recently, hybrid grass systems have started to be used in football fields.

The GrassMaster hybrid turf system, first developed by the Dutch Desso Sports, has started to be used. Hybrid grass is a type of grass that has started to be used in new generation stadiums and aims to minimise weather opposition. Hybrid grass is used instead of natural grass, which is easily worn out due to insufficient air flow and sunlight. Hybrid grass is a hybrid grass type that is formed by combining both natural and synthetic grass. Since natural grass is integrated with artificial grass, a more robust grass emerges. This solid grass does not lift like natural grass and the ground does not deteriorate. Hybrid turf, which is formed by the integration of nature and technology, is also preferred by many big clubs due to its ease of use, durability and longer life (www.grassmastersolutions.com/2023; https://reformsports.com/2023).

A more robust, long-lasting, durable playground is obtained by passing the natural grass roots through the holes of the special production artificial turf to the soil ground. Hybrid grass offers the chance to play comfortably as it does not lift or slip on the ground. Since it is resistant to wear and tear, it minimises treatment and maintenance costs. Hybrid grass provides the

quality of playing on natural grass ground. It provides a less slippery ground than natural grass even in rainy weather conditions. There is no lifting or ground slipping as in natural grass. It maximises the quality of play by offering standard shock absorption resistance, friction, rotational resistance, slip resistance, drainage properties and underfoot stability. It offers a green and healthy field without mud and grass breaks. Hybrid turf field, which is longer lasting and durable than natural turf, provides the opportunity to play and train on the same surface. Therefore, both playing and training can be done on the same field without the need for a training field (www.grassmastersolutions.com/2023; https://reformsports.com/2023).

Figure 18: Hybrid Grass Technology (www.bahceye.com/2023).

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Chapter 8

Innovative Technologies in Volleyball

Beyza Akyüz[1]

Summary

Volleyball is an intermittent sport that involves many explosive movements both vertically and horizontally, where flexibility and coordination are very important as well as strength and power. In order to achieve optimal performance, players must have high quality requirements in terms of physical, physiological and technical aspects.

As in all areas of life, the use of technology occupies an important place in volleyball. Support is received from innovative applications and devices such as wearable technologies, VR-AR, smart devices for physical and physiological monitoring of athletes, directing training programs in the light of the data obtained, preventing sports injuries and improving performance.

Developments in the field of information technologies continue to increase their widespread impact in different areas of life day by day. With the integration of technology into the sports world, the same widespread effect has made a sharp acceleration in volleyball sport as in many sports branches. In the process of training planning and performance evaluation, which extends from technique teaching to performance development, some applications and methods are frequently used in today's technology. Performance measurements, evaluation of measurement results and programming of training in the light of the data obtained, on the other hand, there have been great breakthroughs in issues such as protection from sports injuries.

Volleyball is one of the sports in which technology is used intensively. Data from technological devices used during training provide detailed information about the athlete's movement patterns, physiological processes and performance components (Windt et.al;2020). On the other hand, in a competitive environment, many statistical data can be accessed, such as

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distance covered by the athlete, movement path, successful and unsuccessful attack and defence zones, quantitative data on attack and defence in these zones, ball speed and ball trajectory. In this way, the strengths and weaknesses of the player and the team can be analyzed, the necessary improvements and developments can be made by processing the data obtained and incorporating them into the training programme, and performance can be improved.

Volleyball technologies, from wearable devices to smart balls, from data analytics to video analysis systems, are a growing trend that we see frequently on the courts to meet the needs of the game in all areas. Thanks to wearable sensors, cameras that report location and speed, real-time information about the player can be accessed.

Wearable technologies

Wearable technologies collect input signals from wearable sensors attached to the human body and are often used to monitor and assess exercise load. The devices used in wearable technologies include sensitive sensors, global positioning system (GPS) devices, accelerometers, gyroscopes, and magnetometers (Sousa et al, 2023; Haider, 2020). The use of these devices requires the application of various algorithms and filters. Elite athletes in particular often use these devices to measure external training loads. Total distance is a commonly used parameter in the calculation of external load and GPS data is used in this calculation. The distance travelled is calculated according to certain speed thresholds. Accelerometers, on the other hand, measure acceleration on the X-Y-Z axes and have been used in smart watches and mobile phones for many years (Bergün, 2009; Cardinale, 2017).

In volleyball serving or spiking technique, the angular velocity of the arm during the arm pull, the phase of meeting the ball and then the phase of following the ball, the acceleration, and the ability to execute the movement quickly are important to complete the attack without being caught by the opposing team's block. For this reason, acceleration at the shoulder, elbow and wrist is a parameter that should be measured. It is then important for the athlete's development to include arm acceleration exercises in training. Wearable technology devices include magnetometers and gyroscopes, which measure direction, orientation, and angular velocity respectively. Due to the nature of volleyball and the tactical maneuvers used, the spiker must move at different angles and angular speeds at the net to avoid being caught by the opposing team's block or to surprise the block, while the defender has to accelerate and decelerate in different directions. At this point, instantaneous data from GPS, accelerometer and gyroscope wearable technology devices actually reflect the footprints left by the player during the match.

Wearables and sensors track players in real time, collecting a wide range of data, including metrics such as heart rate, fatigue, jump performance, distance travelled, acceleration and deceleration during training or a match while the ball is in play. Some wearable devices with built-in accelerometers, gyroscopes and magnetometers enable the measurement of load. The algorithm used by the device provides the vertical displacement data of the athlete (Damji et.al, 2021). This is important data for volleyball, where jump height is critical.

As the sensors used are very light and designed not to interfere with the athlete's movement, they have no negative impact on performance. Based on the data collected, performance can be assessed, and the training programme can be adjusted to optimize performance. Biometric T-shirts provide information about the player's posture, body symmetry and muscle fatigue, body temperature and hydration levels through sensors on the shirt. Some groups of wearable devices provide feedback focused on recovery data. This allows the coach to monitor the player's recovery process in detail. The use of accelerometers and gyroscopes, which collect data on acceleration, balance and rotation, is also quite common, providing the coach with information for monitoring and protecting the player in terms of preventing sports injuries, as well as providing biomechanical analysis of the player.

Video analysis system

Vision based methods recognize selected activities using several computers. (Haider,2020) Thanks to high-resolution cameras placed in different parts of the field, the positions in the game are recorded from different angles. This allows the individual performances of the players as well as team tactics to be analyzed and strategies to be determined instantly. Thus, the coach can analyze not only his own team but also the opposing team tactically and take measures against the opponent in order to achieve an optimal result and create a tactical understanding in this direction. Video analysis systems are also used to verify the position in case of team appeals during the referee's decision-making process during the match, which supports the development of a fair match management and sound decision-making mechanism.

During the match, a single interface allows tactical analysis of the teams and instant statistical information to be shared with the bench and the media. This feedback can be used to make immediate changes to the team's tactical maneuvers in order to exploit the opponent's weaknesses or to take measures against the opponent in the coach's own team order. With this invaluable information at your fingertips, the fate of the match can change at a moment's notice.

Movement analysis provides data such as the way the athlete uses the technique or the frequency of the movement. Metrics such as distance covered during training or competition, number of sprints, frequently performed movements are analyzed and in this way the athlete's training load can be calculated. An injury analysis can be obtained by comparing the athlete's movement analysis, frequently performed movements, training load data with periods of sports injury. The aim is to use the data obtained to reduce the risk of sports injuries. In other words: o Movement patterns that can lead to overuse injuries can be identified and corrective action can be taken. These systems not only improve the player's performance but also minimize the risk of injury.

In addition, volleyball-specific analysis programmes are often used, allowing coaches to create small clips from uploaded game footage, add annotations, share, and work with team players, and enable communication between coaches. It provides player performance statistics, match reports and player feedback.

An important aspect of the technologies used in volleyball is the need to be able to determine the camera position with a high degree of accuracy without having to make any changes to the court, ball, or net. For this reason, the use of multi-camera systems has become widespread. The best known and most widely used multi-camera system in tennis is the Hawk-Eye system. This system estimates the position of the ball in each set of frames collected (Szelag, et.al 2019).

In volleyball, many algorithms have been used to track the ball or the player in match analysis. Even machine learning is used in some algorithms. If we have to define machine learning, we can say that it is computer programs that can improve their processing power by themselves based on experience. When the effect of athletic level of volleyball players on decision making, accuracy, reaction time and cognitive level in hitting, landing, and blocking was analyzed by machine learning method, it was concluded that the higher the athletic level, the less the players were affected by other factors (Yu et al, 2022). However, factors such as motion blur due to ball speed, low camera frequency or noisy ball contour (excessive exposure time causes blurring and stretching of the ball contour), lighting or changing environmental conditions (player and spectator movements in the background) can reduce accuracy.

For match analysis, some software is used to analyze the percentages of players and positions during the match. The software provides information on the percentage of successful and unsuccessful moves in parameters such

as attacking combinations (side-out and counterattacking), ball reception, defence, block, service, digs and setting. In addition, a statistical report is obtained about the success percentages of players or teams and positions on the court (Kurowski et.al, 2018; Silva et.al, 2014).

Hawk eye and Challange system

The Hawk Eye and Challenge System has been a popular image analysis system for volleyball matches in recent years. The fast pace of the game makes it difficult for referees to make decisions. This situation is sometimes a topic of discussion for the teams and spectators and can lead to tension in the competition environment, increasing the pressure on the referees. For this reason, the use of Hawk eye and challenge systems has been introduced to make decisions in critical situations more reliable and referee decisions more objective and has made a great contribution to the sport of volleyball.

It is sometimes difficult for the referee to decide whether the ball is in or out when it is travelling at high speed. The Hawk Eye system has been used in many industries for a long time. It is an accurate and reliable system, and the aim of Hawk Eye is to monitor the trajectory of the ball throughout the match (Singh & Dureja, 2012). Thanks to this system, information such as whether the ball is in contact with the line and the distance to the line can be clearly seen by the cameras that monitor the lines of the pitch.

The challenge system has been used by the Turkish Volleyball Federation since the 2017-2018 season. According to the rules of the game, at the end of a rally, if one of the teams disagrees with the referee's decision, it can request a challenge according to the rules. The actions that can be requested are ball in/ball out, block contact, net contact, line violation (service line, attacking line, centre line) and four balls. Teams have two appeals per set. However, if the teams' objections are justified, their right to appeal continues throughout the set. (TVF, 2018).

According to the results of the requested challenge analysis of the Turkish Volleyball Federation (TVF, 2019) for the first half of the 2018-2019 season, it was reported that 612 challenges were requested in 132 matches played in the first half. In 370 (60.46%) of these challenges, the referee's decision was correct and in 242 (39.54%) of these challenges, the teams were correct. Teams requested challenges 1.24 times per set and 3.73 times per match. Challenge results were displayed on the screen in an average of 39.5 seconds. According to the statistics, the time used for challenges was 2.86% of the total time. According to the challance results, it was determined that 85% of the referees were right about centre line and attacking line infringements

and 67% of the teams were right about aerial contact (TVF, 2019). In another study on team appeals and referee justification rates in the use of the challenge system, an analysis of challenges was conducted, and referee justification rates were determined for the 2020/2021 and 2021/2022 women's and men's Super League competitions. The challanges made by the teams were analyzed with the Video Evaluation System (GDS) and it was stated that the rate of justification of the referee's decisions was higher than the teams in decisions other than four strikes, and it was also stated that technological tools that help the referee's decision have a positive effect on the referee's performance (Akarçeşme, 2023; TVF, 2017; TVF, 2018).

Virtual Reality (VR)

Thanks to Virtual Reality (VR) and Augmented Reality (AR) simulation technologies, players can train in a simulated volleyball match in a virtual environment, without the pressure of a real competition, experiencing different scenarios and developing strategies to suit the situation. The technique used can be visualized from different angles and focused on more detail. Individual and team tactics for competition can be repeatedly practiced in visual form. VR can also enable coaches to give real-time feedback to players and train them remotely.

Augmented Reality (AR)

During a volleyball match, real-time statistical information about the players or the game on the screen increases the motivation and enjoyment of the spectators. The spectators feel more involved in the game and can better understand the details of the game. In addition to statistical information, AR can also be used to model players' positions and analyze strategies. When we talk about the contributions of AR and VR technologies in volleyball, we can mention the increase in repetitions for the player, the development of muscle memory and thus technical development, the possibility of identifying new strategies and trying them out for the coach, and the possibility of being more involved in the game and increasing the enjoyment of watching for the spectators.

Smart Equipments

The use of technology in volleyball is not limited to observing, measuring, and evaluating performance, but many smart devices are also used to improve technique. One of these is the smart volleyball. In particular, the serve, which can be considered as a kind of attacking method because it is the first movement that starts the game, has a very important place in today's volleyball. The ace points that the players get directly from the serve

are important both in terms of scoring and team motivation. From this point of view, the information that can be obtained about the point at which the ball is hit, that is, the falso to be given to the ball and the speed of the ball, is advantageous in terms of improving the serving technique. This is where technology comes in, and smart balls equipped with smart sensors come into play. Thanks to these sensors, data on the speed, direction, spin and impact points of the ball help coaches to improve technique (Zhang et.al, 2022). Not only the speed but also the accuracy of the ball is important when serving or dunking. Therefore, having information about the trajectory and speed of the ball allows the player to improve the technique in these parameters. On the one hand, the devices that have been used for years to measure the speed of the ball are now being used to measure the speed of the serve or dunk. Smart coaching platforms, which allow coaches and technical staff on and off the court to communicate with each other to make immediate changes and adjustments to the course of the game, are also becoming more common.

Artificial Intelligence

Artificial intelligence, which was developed as a sub-science of computer science and whose use is increasing every day in many fields, from healthcare to the automotive industry and education, is also being used in the field of sport. It is based on the development of behavioral and computational systems that allow data to be collected in situations of perception, reasoning, learning and decision-making. For example, the mental training used by volleyball players is of great importance in achieving optimal results and improving performance. It is believed that maintaining the players' psychological modes at a certain level will contribute to the optimization of their sporting skills. In this context, an artificial intelligence model has been developed to increase the accuracy of mental training models. This model is based on artificial intelligence calculations and aims to predict neural networks, short-term memory, and long-term memory (Jin, 2022). On the other hand, Shih et al (2022) categorized the artificial intelligence-based smart technologies used in volleyball under 3 main headings and listed them as monitoring, evaluation, and diagnosis respectively. Monitoring is defined as the monitoring of the athlete's physiological data, while evaluation and diagnosis is the evaluation of the data obtained from the athlete using artificial intelligence, discovering the athlete's potential, and making a judgement about it. As a result of all this process, it was stated that players receive immediate and accurate feedback during the training process with intelligent technology, which has a positive effect on learning.

Promotion and Dissemination of Sports

Thanks to Augmented Reality (AR) or various interactive applications, spectators can watch the game as if they were there, even if they are not in the competition area, and feel involved in the game and the environment.

In addition, the statistical information about the athletes and the tactical analysis of the game projected on the screen during volleyball matches increases the spectators' understanding of the game, makes them feel more involved in the game and allows them to follow the game as they understand it. With the increasing number of spectators, it helps to increase the audience and popularity of the sport.

CONCLUSION

As a result, the integration of volleyball with technology has made a significant contribution to enriching the experience of players, coaches and even spectators. Increasing the technical capacity of the player by analyzing performance, identifying, and improving weaknesses, and making appropriate strategic moves immediately to achieve the optimal result are among the results provided by the use of technology in volleyball. On the other hand, it is crucial to determine the training load, given that overloading can lead to sports injuries. Therefore, it is necessary to determine the training load in a healthy way and to plan the training within this framework. At this point, technological devices provide the opportunity to make valid and reliable measurements (Windt et. al, 2020).

The role of technology in the development of game dynamics and tactical strategies, in ensuring the interest and followership of spectators, in bringing sport to the masses and popularizing it cannot be denied. In parallel with the rapid development of technology in the coming times, it is a matter of curiosity what kind of technological devices and applications can be used in volleyball.

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Chapter 9

Innovative Developments in Basketball: Utilization of Technology

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Abstract

This research explores the transformative impact of the integration of technology in basketball, both on and off the court, from training and performance enhancement for athletes, coaches and conditioners, to data analytics for statistical coaches, administrators and spectator engagement. It also highlights the importance of the use of technology in player development, equipment development, injury prevention, pre-game and in-game strategies, and team-fan interaction, as well as the fact that technology not only improves the overall quality of basketball but also opens new avenues for growth and innovation in sport.

INTRODUCTION

The integration of technology into sport is effective on improving athletes' training, performance, and strategy development methods. The huge impact of technology on sport is closely related to multifaceted developments, including athletes, coaching methodologies, management and spectator involvement, as well as its implementation and currency. With the advancement of technology, the variety and quality of equipment used in the sports environment has increased (Ak, 2021), and many new technologies that are of great importance to improve the technical performance level of athletes, reduce sports injuries, increase game viewing, attract fans, and promote the development of basketball-related industries have begun to be applied in basketball training and competitions.

Basketball, a team sport characterized by high-intensity running, displacements, accelerations, decelerations, sprints, continuous changes of direction, jumping and special technical skills (Abdelkrim et al., 2007;

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Abdelkrim et al., 2009; McInnes et al., 1995), generally characterized by increased physical demands, high intensity and fast movement patterns (Deitch et al., 2006), is one of the most popular and widely played sports in the world.

Basketball has a 130-year history, invented in 1891 by James Naismith, a professor of physical education in Springfield, Massachusetts. In particular, the National Basketball Association (NBA) is recognized as the highest level professional basketball game in the world (Li, & Xu, 2021). With the implementation of effective training strategies dependent on a variety of factors influencing individualized external demands and internal responses (Schelling and Torres-Ronda, 2013), it is crucial to promote physiological adaptations that enhance performance (Akubat et al., 2014). The fundamentals of competitive basketball are undergoing a process of continuous development to improve and create basketball style and develop areas of understanding (Li et al., 2021).

Much progress has been made over the years thanks to the integration of technology into the discipline. Technological innovations offer various opportunities for players, coaches, managers and analysts to explore the intricacies of the game, recognizing their contribution to individual and team performance, injury prevention, coaching strategies and the transformation of the game. In particular, performance predictions using current and previous data on players (Senderovich et al., 2018), knowledge of each player's advantages and disadvantages can provide added value, especially for managers and coaches, in terms of roster formation, new signings, changing the rhythm during games, and other vital qualitative and quantitative factors (Sarlis et al., 2021).

Technological developments, which have positive effects such as facilitating the lives of individuals and using time effectively (Camkıran et al., 2021), have led to different and innovative training tools such as virtual reality simulations, wearable devices, artificial intelligence and biofeedback systems. These devices help players to improve their skills, increase their stamina and monitor their performance metrics.

Tactical Strategies, Athlete Development Tracking, and Athletic Performance Analytics

Technological developments that have positive effects such as making individuals' lives easier and using time effectively (Camkıran et al., 2021), virtual reality simulations, wearable devices and biofeedback systems have created different and innovative training tools. These tools help players to

improve their skills, increase their endurance and monitor their performance metrics.

In the context of basketball, various statistical techniques are applied for a multitude of purposes, such as defining the fundamental characteristics of a game in the simplest way through descriptive statistics (Kubatko et al., 2007), predicting the outcome of a game (Manner, 2016; West, 2008), as well as analyzing the performance of athletes (Deshpande & Jensen, 2016; Page et al., 2007) and resolving more complex situations, such as determining and implementing optimal technical-tactical strategies.

With the advent of player tracking systems, teams can now capture large amounts of data during live games. These systems record players' movements, positions, shooting accuracy and numerous other variables. The emergence of advanced metrics and analytics in basketball has revolutionized the way teams strategize, enabling data-driven decision-making in player selection, game planning and in-game adjustments (Drazan et al., 2017). State-of-the-art performance analyses (Weith et al., 2023), allow coaches and analysts to make data-driven decisions, optimize player rotations, and develop more effective game plans (Terner & Franks, 2021).

A review of the literature shows that there are significant differences in activity frequency and intensity between players at different levels of play (Stojanović et al., 2018), examining the physical demands of basketball using video-based motion analysis methodologies based on subjective visual prediction of sport (McInnes et al, 1995; Oba & Okuda, 2008; Scanlan et al., 2012; Scanlan et al., 2015), contributing to the field by aiming to collect all appropriate analytics used in sports as state-of-the-art performance indicators through sports data for decision making for basketball games, teams and players (Sarlis & Tjortjis, 2020). Therefore, elite basketball practitioners should be provided with reliable scientific data, while studies on youth teams or semi-professional players should be interpreted with caution (Svilar et al., 2019).

Through sophisticated statistical models (Geard et al., 2021) to assess teams' player performance, metrics such as player efficiency rating, true shooting percentage and box plus-minus provide a deeper understanding of players' contributions beyond traditional statistics. Coaches and players have access to real-time data during the game, allowing them to make adjustments to strategies on the spot. Analytical dashboards provide insights into shooting percentages, defensive coverage and ball possession efficiency, aiding decision-making in critical moments (Lath et al., 2021).

Wearable Technology in Basketball

With the changes and developments in science and technology, the use of mobile technologies (Fang and Chang, 2016), smart systems have been rapidly developed, and the availability and speed of use of wearable sensor technology has also increased rapidly (Yuan et al., 2021). The availability of this technology, reduced costs and ease of inclusion in different criteria within sport are among the reasons for its widespread use.

Wearable technologies are small electronic and mobile devices that can be worn on the body as part of devices, accessories or clothing, enabling the collection of a wide range of data that can be processed and analyzed by artificial intelligence systems (Chidambaram et al., 2022). These technologies provide real-time data on players' physical characteristics, movement patterns and physiological responses during training sessions and games (Russell et al., 2021; Vazquez-Guerrero et al., 2019). For example, wearable devices based on GPS trackers, heart rate monitors, accelerometers and flexible pressure sensors (Luo et al., 2020) have become an integral part of modern basketball training and performance assessments (Facchinetti et al., 2023). On the other hand, basketball shoes with state-of-the-art materials and designs (Luczak et al., 2020) improve player safety and performance by reducing risk and optimizing player movements (Du, 2021; Luczak et al., 2020). Wearable technology can be used to detect sport-specific movements by identifying repeated and recognizable events (Benson et al., 2018; Chambers et al., 2015; Liu & Liu, 2023; Willy, 2018), which can provide professional analytics for basketball games and better formulate defensive and offensive strategies and tactical development, as well as reduce athletes' injury risks (Ferioli et al., 2018). Coaches and trainers can also benefit from this data. By analyzing data from wearables and training equipment, teams can make informed decisions about rest periods, training intensity and recovery strategies.

Technology has a very important role to play in injury prevention and rehabilitation for basketball players. Biomechanical analyses, pedabarographic analyses, and motion capture technology and wearable sensors, as one of the critical sensing components, can be used for human medical diagnosis, medical monitoring (Dai et al., 2022; Lee et al., 2019; Luo et al., 2020; Aydos, 2023; Pekel and Aydos, 2022), helping to identify risky movement patterns, enabling players and medical staff to address potential disability issues before they escalate (Castro et al., 2008; Taylor et al., 2019). From cryotherapy rooms to wearable recovery devices, technology plays a crucial role in optimizing players' recovery, reducing downtime and ensuring peak

performance (Banfi et al., 2010; Jinnah et al., 2019). Injuries are the biggest concern for teams, management and fans, especially the players, as they can significantly affect overall team performance (Talukder et al., 2016).

Despite the development of prevention and rehabilitation strategies, injury rates are still high, so injury risks need to be predicted and reduced (Kaplan et al., 2019). Biomechanical analysis equipment can help identify movement deficiencies and potential injury risks, and when integrated into training programs, can improve athletes' performance and minimize the likelihood of injury.

Intelligent Basketball and Video Analytics

Integrating sensors into basketballs allows precise monitoring of shooting, dribbling and passing accuracy, providing valuable data for training and technique improvement (Fan et al., 2021; Fan et al., 2022; Huo, 2022). The use of dynamic sensors in sport can help improve performance and develop personalized training plans by providing a precise measurement of athletes' activities and equipment dynamics (Straeten et al., 2019). Basketball generally requires repetitive exercises based on the player's consistent movements (Guo et al., 2021), and a microcontroller attached to the basketball can be used to make the measurements required for progress monitoring (Fox et al., 2021). Several studies have been conducted to determine training demands using time-motion analysis based on artificial neural networks and mobile smart sensors (Abdelkrim et al., 2010; Bishop & Wright, 2006; Conte et al., 2016; Hulka et al., 2014; Klusemann et al., 2012; Klusemann et al., 2013; Narazaki et al., 2009; Torres-Ronda et al., 2016; Yuan et al., 2021).

Advances in video analysis software allow coaches to assess players' skills and strategies (Garhammer and Newton, 2013), identify athletes' strengths and weaknesses, and develop specific strategies to improve individual and team performance. Due to its rich multimedia content and commercial availability (Chakraborty and Meher, 2013), the analysis of sports videos focuses on the characteristics of computer vision techniques used to perform the specific operations to which they are assigned, such as detailed complex analyses such as the detection and classification of each player according to his team (Naik et al., 2022).

In recent years, with the popularity of video capture devices and the continuous development of computer vision techniques, sports experts agree that the use of digital video analysis technology in sports can greatly improve training efficiency (Chen & Wang, 2020). The use of computer vision and

deep learning technologies has increased the number of applications of depth cameras in human-computer interactions, automated driving, virtual reality, etc. (Ma et al., 2021), and human action recognition datasets in RGB image data and Depth data (RGB+D) format have also emerged (Zhang et al., 2016).

Perhaps the most popular alternative for developing decision-making, prediction and pattern recognition skills in team sports is the use of video simulations in which athletes watch video replays of previous performances and/or games played by professionals (Pagé et al., 2019). Through these video simulations, the effectiveness of this training method has recently been the subject of significant research (Broadbent et al., 2015; Cotterill & Discombe, 2016). A wide range of sports data such as shots taken, fouls committed, defensive measurements during the match, and kilometers run, as well as many other parameters of the match can be tracked using cameras (Sarlis & Tjortjis, 2020). In addition, sports video behavior recognition technologies can achieve excellent results in the general visual recognition problem based on images (Guo, 2021; Jalal et al., 2020; Wu et al., 2019).

By embedding object tracking methods into the algorithm to mark individuals (Wu et al., 2019), video content analysis has rapidly evolved in the application of large datasets (Rana et al., 2014; Soomro et al., 2012). In general, the technical action analysis algorithm based on video keyframe can be used to evaluate the player's motion technology, realize the high-efficiency evaluation system of human-computer interaction, and improve the evaluation efficiency of player action video (Chen & Wang, 2020). In addition, high-resolution cameras and motion capture systems enable in-depth analysis of players' movements. By studying biomechanics, coaches can identify inefficient or risky movements that can lead to injuries. This information can help coaches design training programs that reduce the likelihood of injury and improve performance.

Artificial and Virtual Reality - Artificial Intelligence

Virtual reality technology is a kind of technology in which the computer is used to create a simulated environment, and a lot of sensing equipment is used to help users enter the environment to enable users to realize direct natural interaction (Katz et al., 2006; Neumann et al., 2018; Suri et al., 2023; Yao et al., 2012). As in many areas of society, an increasing amount of data has been collected in all areas of sport, and automated data analysis has become an important and rapidly developing field (Claudino et al., 2019).

Perhaps the most popular alternative for developing decision-making, prediction and pattern recognition skills in team sports is the use of video simulations in which athletes watch video replays of previous performances and/or games played by professionals (Pagé et al., 2019). Virtual training platforms have emerged by providing immersive experiences for players to fine-tune their skills, study opponents, and simulate game situations (Tsai et al., 2020). Lorains et al. (2013) reported that a video simulation training program was positive for team sports on the field. Such devices can enable athletes to improve their technique and decision-making processes, resulting in more versatile and adaptable players. Artificial and virtual reality technologies offer immersive training experiences that allow players to simulate game scenarios and practice decision-making in a controlled environment (Pagé et al., 2019; Richard et al., 2022; Song, 2021). By analyzing their movements, field awareness and tactical choices, players can bridge the gap between training sessions and real games (Jiang & Zhang, 2022; Soltani & Morice, 2023).

From the spectator's perspective, they can experience basketball games like never before through virtual reality technologies, providing immersive experiences and interactive engagement opportunities. Multiple camera angles, instant replays and augmented reality overlays provide an immersive viewing experience, bringing fans closer to the action. Virtual reality, a visually-based computer simulation of a real or imagined environment in which the viewer can interact with the simulation (Craig, 2013), can enhance the visual fidelity of the video simulation and give viewers a greater sense of immersion in the action (Pagé et al., 2019). For example, many media now use virtual reality to present videos where the viewer can see the entire 360-degree scene around the camera by wearing a head-mounted display that adjusts the image in real time according to the orientation of the viewer's head (Brault et al., 2015; Craig, 2013; Miles et al., 2012).

In addition to artificial reality and virtual reality, artificial intelligence, which is one of the biggest examples of advanced technology in recent times, has recently become the main subject of research in sports sciences. Designing and building intelligent agents that take orders from the environment and perform actions that affect that environment (Helm et al., 2020) is defined as a new technical science that researches and develops theories, methods, technologies and application systems to simulate, extend and extend human intelligence (Sukumaran et al., 2022; Taborri et al., 2021).

The United States is considered a pioneer in the use of AI in sport, both in research and practice. Artificial intelligence has been used for game and

player analysis for several years, especially in American football and baseball (Li, & Xu, 2021), and is gradually leading technological development in different disciplines. For example, research has shown that analyzing various types of data can help support coaches' tactical decision-making (Herold et al., 2019) as well as training and competition planning (Me & Unold, 2011). This type of analysis has great potential to prevent injuries (Claudino et al., 2019).

DISCUSSION AND CONCLUSIONS

The far-reaching impact of technological developments is evident in different disciplines of sport. In this context, the integration of technology in basketball is not only limited to the quality of the game, but also has an important place in terms of player development, technical-tactical strategies, injury reduction and fan enjoyment.

As technology continues to evolve, ushering in a new era of data-driven performance and strategic decision-making, it will be crucial in ensuring a bright and sustainable future for basketball. By providing players with state-of-the-art training tools such as virtual reality simulations and wearables, allowing them to improve their skills, increase their stamina and monitor their progress, technology allows athletes to analyze their performance data to identify areas for improvement and adapt their training routines accordingly to perform better overall on the field. For coaches, advanced analytics and sports simulation software can enable them to make data-driven decisions, develop effective game strategies and adjust tactics based on real-time performance data. Also, with advanced analytics and video analysis tools, it has become easier to identify promising players and assess their potential. From wearable devices, to athlete development, to technical-tactical strategies for coaches, continued technological development has made basketball more accessible worldwide, on and off the court. Together with live streams, online tutorials and digital resources, players from different regions can learn and improve their skills regardless of geographical obstacles. As fan experiences become more effective through augmented reality and virtual reality, a deeper connection between spectators and sports can be established.

In conclusion, for the growth and development of basketball, the use of technology in basketball plays a crucial role in pushing the boundaries of what the sport can achieve, from enhancing athlete performance to technical-tactical strategies and spectator engagement. By embracing technology responsibly and addressing ethical considerations, basketball can continue

to thrive, captivate audiences and inspire generations of athletes around the world. Looking ahead, the potential for technology development in basketball, advances in artificial intelligence, virtual reality and advanced analytics, and the internalization of these innovations, along with further studies on player performance and tactical strategies, will undoubtedly shape the future landscape of basketball.

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Chapter 10

Tech in Rec: Technology Use in Outdoor Recreation

Elvan Deniz Yumuk[1]

Abstract

Technology has always been a big part of human life. Since the time when we started using tools, we have ignited a fire which is today called technology. Technology is being used not only in the daily life, but also in the activities that individuals do in their leisure. One of the leisure activities that is popular and attractive to people of all ages is Outdoor Recreation activities. Outdoor recreation activities provide the participants thrill, risk, and adventure that they seek. However, the use of technology in outdoor recreation is a significant aspect as it provides safety to some point, navigation skills, comfort, and motivation. Therefore, the aim of this chapter is to investigate the technology use involved in the outdoor recreation activities. Thus, in this chapter the technology involved in outdoor recreational activities is discussed in different aspects as a motivator (social media and image), as a comfort (development in materials used), as a performance auditing device (wearable technology and tracking apps) and as simulation (virtual reality and augmented reality).

Introduction

Use of technology in sports has always presented a golden opportunity for the participants no matter if they were chasing performance or looking for a way to do exercise more comfortably. This can be considered in terms of professional sports as well as recreational sports. Of course, recreational activities can be categorized in different ways such as individual or group activities, therapeutic activities, workplace or campus activities, simple tourism acts or sports tourism activities, indoor or outdoor activities (Tribe, 2015). So, the use of technology in all these recreational activity types are different and getting more and more users all around the world.

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One example is the outdoor recreation which has become more and more popular among individuals since the COVID-19 which had a frustrating and harming impacts killing millions and affecting health, social dependence, and economics (Robets, 2020). Why outdoor activities became the salt of the earth is because it gave individuals the distance that they need and the physical activity that they crave for. Now, more and more people are still choosing to chase outdoor thrills through outdoor recreation opportunities provided. Naturally, this brings the subject to the concept of outdoor recreation.

Outdoor Recreation (OR) is both an old and a new concept when considered in different aspects. It is an old concept because people have been doing activities out in the nature for as long as they existed. However, it is a new concept due to the technological advances happening in the field. Of course, these technological advances have changed the face of the Outdoor Recreation for the people enjoying it. The changes occurred in many areas such as maps, GPS, wearable technology, digital apps that can be downloaded in smartphones, and the equipment. These advances brought about advantages for the people who participate in the activities carried out in nature and natural environments since the mother nature can make individuals face with many adversities as it is. Nevertheless, the right equipment and right technology use can turn these adventure seeking activities into a more achievable and enjoyable experience rather than just a risky movement.

The OR is also a vast area which includes many different recreational activities that can be carried out in land, air, and water. The land-based OR activities include but are not limited to the activities such as hiking, Nordic walking, trekking, camping, mountain biking, rock climbing, ice climbing, mountain climbing, trail running, mountaineering, orienteering, abseiling, horse riding, skiing, and snowboarding. On the other hand, air-based OR activities include powered/non-powered hang gliding, powered/non-powered paragliding, ballooning, kiteboarding (which is both air and water based), BASE jumping, bungee jumping, skydiving, and wingsuit flying. Finally, water based OR activities can include swimming, sailing, kayaking, scuba diving, fishing, windsurfing, white water rafting, jet skiing, parasailing, and stand-up paddle boarding which has recently been attracting many participants all around the world. All these activities have unique features which require unique equipment and unique technology. Therefore, in this chapter the technology involved in outdoor recreational activities will be discussed in different aspects as a motivator (social media and image), as a comfort (development in materials used), as a performance auditing device

(wearable technology and tracking apps) and as simulation (virtual reality and augmented reality).

Technology use in outdoor recreation as a motivator

Participating in outdoor recreation is associated with using adventure as a tool to overcome the socio-cultural barriers (Brymer & Schweitzer, 2013) and having illusion of cheating death (Schrader & Wann, 1999). As a motivator, participating in outdoor recreation and using the social media to advertise can be explained through motivation theories. Only the participation can be considered as the inner/internal motivation which includes thrill, fear, control, skills, achievement, physical fitness and risk. As internal/external motivation, nature, art of nature and spirituality can be both felt inside and be expressed on the social media. The external motivation here can be expressed as friends, image, escape and competing (Buckley, 2012) which are the popular phrases and hashtags used on the social media platforms by the users in order to describe their posts related to outdoors and nature. Also, gratification theory is also used by academics to explain the social media use and motivation. The theory approaches the social media use in ten ways which are social interaction through social media, seeking information, passing time on social media, looking for entertainment, using social media platforms for relaxing, expressing opinions, communicating, convenience utility, sharing information with others and getting knowledge about others (Whiting & Williams, 2013). From that perspective, the use of social media while in outdoors or while deciding about what to do in outdoors or where to go can be seen as a motivator.

Today, we are all engaging people through social media showing where we eat, where we drink, where we swim and what we do with our immediate circles. The number of users is getting higher everyday (Abi-Jaoude, Naylor, & Pignatiello, 2020). Generally, the research on social media use reveals negative effects on mental health, depression, anxiety, and body image (Beyens et.al., 2020; Kadam & Atre, 2020; Keles, McCrae & Grealish, 2020), and no doubt individuals need education in social media and technology use in our digital age (Valenzuela, 2020); however, not all the people use the social media in their disadvantage. There are some social media accounts providing information about the outdoor opportunities. Additionally, capturing an Instagrammable photo is a big motivation for outdoor lovers (Arts, Fischer, Duckett & van Der Wal, 2021). Flickr is another social media platform in which people share their photos in order to get followers. A study on Flickr users photo sharing situations in outdoor recreational areas such as parks revealed that these individuals not only posted themselves in the process,

but also overall shares included a sea of information related to the activities being carried out and different interests (Song, Richards & Tan, 2020). Another study on female representation in the outdoors on social media mentioned that being female and being in the outdoors do not necessarily match in the eyes of society. Outdoor activities are generally considered a male-dominant type of activities. However, the study revealed that some participants aimed to present a meticulous outdoor identity as an active participant and challenge the gendered and heteronormative perception of the society (Low, Miller, Doran & Hardwick, 2022). So, the social media is here used as a motivation to have a voice the field which is considered masculine.

On the other hand, individuals express their love of nature through social media. A study on social media, nature and life satisfaction showed interesting hashtags while posting photos of nature in the social media. These were as follows: nature, natural landscapes, tree, plant, water, forest, bird, highland river, sea, wilderness etc. (Chang et.al, 2020). Expressing how they are having fun and what outdoor activities mean to them can be both a motivation for the account owner and a motivation for the followers.

Another point where social media is a motivator is the interest groups on platforms such as Facebook, Instagram, Twitter, Flickr, YouTube, personal blogs, and websites. Today, the term "google it" is used by everyone to mean that search it on search engines such as Google, Opera and Firefox. Outdoor recreationists or enthusiasts can search anything they want to learn about using these search engines. They can also be a member of a group which is in their interest as well (see Figure 1).

Figure 1. Interest Groups on Social Media Platforms

To give an example, a hiking enthusiast can join a hiking group on one of the social media platforms, follow their trips and events, share their own knowledge about hiking, interact with people and make friends, or join them in a trip (see Figure 2.).

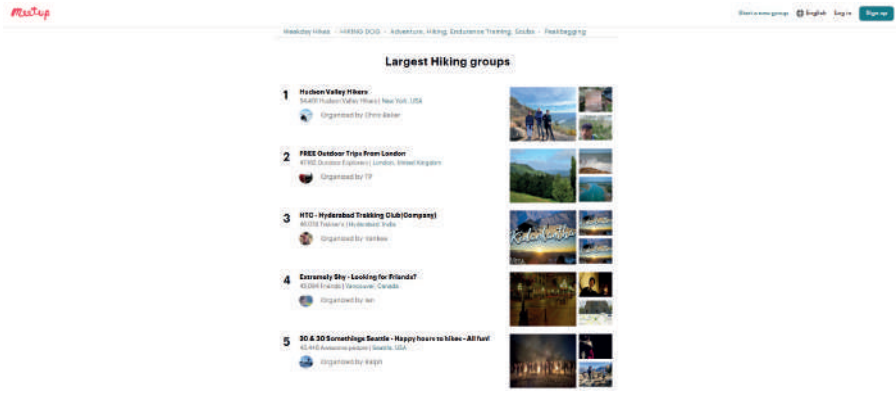

Figure 2. Hiking Blogs

A camper can learn how to tie knot by just writing "how to tie knot" on google and get information about different ways of tying a knot (see Figure 3).

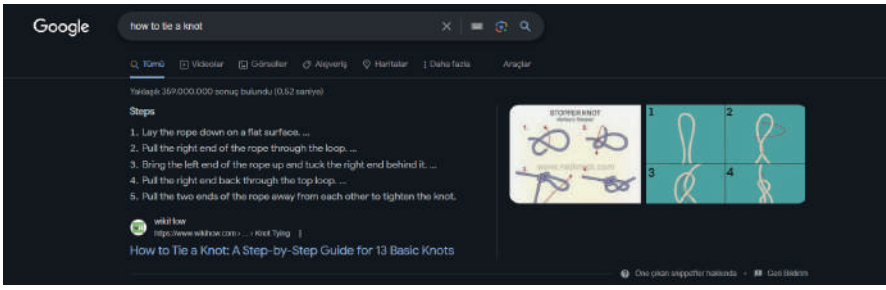

Figure 3. Searching about Information Related to Outdoor

Another outdoor recreationist can share their experience about an activity they do and inform other about how to get to the place, what to do their, how much they should spend, and what equipment they should have while doing this particular activity (see Figure 4).

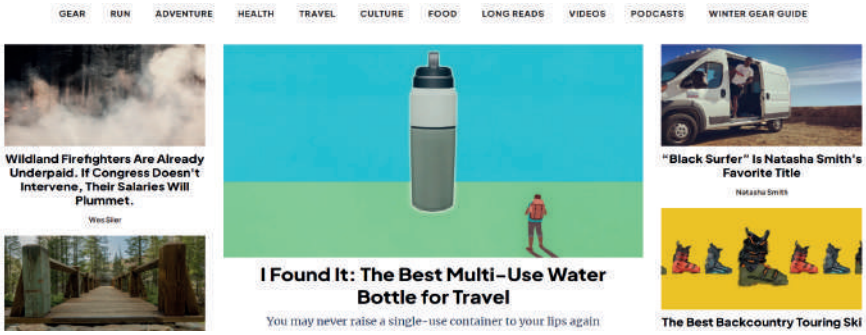

Figure 4. Outdoor Experience Sharing Websites

If they are not familiar with the environment, they can search for the outdoor activities that can be done in the district (see Figure 5).

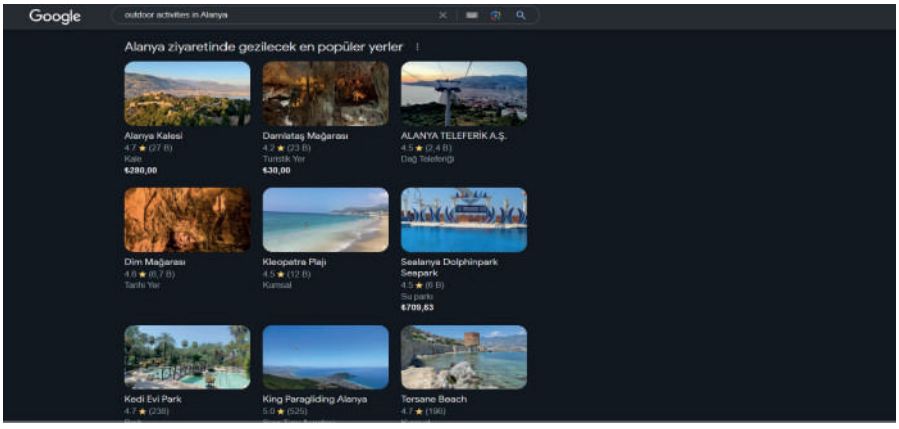

Figure 5. A Google Search about Outdoor Activities in a Particular Area

As can be seen, when used in advantage, social media is not about creating depression and anxiety, but about providing and receiving information about the subject of interest. These positive sides of technology use in outdoor is the motivating factor for the individuals participating or considering participating in the outdoor activities.

Technology use in outdoor recreation as a comfort

As mentioned before, the use of technology in outdoors is not new and can be very crucial to the lives of humans. Let's think about the first humans on earth, they built tools to survive and use those tools to their advantage to create today's society. Our ancestors had curiosity and exploration, and

we have it in our DNAs. When considering technology, one should not only think about the digital technology but also should think about materials evolution throughout the years. For example, as an outdoor hotel, tents have been providing campers who are sensitive to nature (Doğantan, Gülenç & Kozak, 2017) to have a vacation in different locations. Whereas at first, individuals used to utilize canvas tents (Harmon, 2001) which consist of guy lines, tent fabric, metal poles and stakes, today tents are much more efficient to be used in any weather conditions. The development of the ticking (the fabric used to make tents) allowed campers to camp under the rain, in very cold environments, or under the burning sun (see Figure 6). Also, today the technological advances allow campers to see their ways in the dark since they can use flashlights. Sleeping bags, today, can be used in -40^{o}C which make it easier for campers to have a good night sleep under the snow. Having a fire lit in the nature used to be problematic; however, today campers can use small propane cylinders not to harm nature in any way possible.

Figure 6. Contemporary camping materials

Another way to consider technology use in outdoor recreation as a comfort is the materials that are worn while in the natural environment. As the technology reached a certain level, the materials individuals wear became more and more comfortable to the users liking. In addition, research has been carried out to develop the materials meeting the expectations such as optimal skin temperature, comfort during activity, appearance and color harmony, and aesthetics (Park, Park, Lee & Ra, 2001). Among the outdoor recreationists the keyword for the outdoor wear is "functional" (Je, 2012). The outdoor wear should satisfy the users in the harsh conditions in the nature or the natural environments. Whereas there is a traditional approach to development of outdoor wear, there are ideas about turning wearable products (such as jackets) into tents in order to let the users one less item while

going camping (Wang, 2014). A study on outdoor wear revealed that for the extreme outdoor recreational activities, individuals prefer an ergonomic pattern of design for easy activity as well as functional materials that can adapt to the air conditions. On the other hand, individuals who participate in outdoor activities such as trekking and hiking, the important thing is portability and easy storage (Yoon & Roh, 2021). What is also significant for the users is moisture absorption and fabric breathability (Lee, 2010). Zhang et.al. (2022) carried out a study on perfecting running, hiking, trekking and similar outdoor footwear inspired by ostrich foot which enhances the comfort and performance of the participants. The results showed that the enhancements in the bionic cushioning unit in the heel area provided positive results for the users. However, a study carried out on the climbers revealed opposing views in terms of technological developments in the area of climbing (Barratt, 2011). Some climbers thought that the technological advances in both wears and climbing equipment has made the experience of climbing safer and helped improve climbing experience, whereas the others thought that individuals climbing became more dependent on the technology and were losing their skills. All in all, individuals today use the technological advancements to their advantage in the outdoor recreation activities to achieve comfort while doing challenging activities.

Technology use in outdoor recreation as a performance auditing device

The technology can be used in the outdoor recreation activities for auditing the performance as well. Many smart devices have been developed with which individuals engaging in outdoor recreation activities can use to measure the duration of activity, to see calories burnt, to track outdoor workouts (GPS), to monitor their heart rate, to count their steps, to check their blood oxygen levels and blood pressure, to have an altimeter and compass. Among these smart devices, there are watches, headlamps, cameras, belts, bracelets, and glasses. In the context of outdoor recreation, all these devices provide different opportunities. Individuals interested in outdoor recreation can download applications on most of these devices to audit the aforementioned parameters. To begin with, there are some applications which help the users to track their outdoor workouts. Some of those are Wikiloc, Map My Hike, AllTrails, Komoot, Hiking Project, Gaia GPS, Green Tracks, A-GPS Tracker, Strava and AlpineQuest GPS Hiking Lite. These apps include services such as routes for mountain bike trails, hiking trails, road bike trails, bicycle tour trails, off road trails, alpine climbing trails, trail running trails, walking trails, backcountry skiing trails, road motorbike trails, dual-sport motorcycle trails, kayak/canoe trails, snowshoe trails, quad trails, car trails, sailboat trails, cross country ski trails, and horseback riding trails (see Figure 7 and Figure 8).

Figure 7. Tracker App Wikiloc

Figure 8. Trail Map Example on AllTrails

On these apps, the users can share their own routes as well as follow the routes explored by others (see Figure 9 and Figure 10).

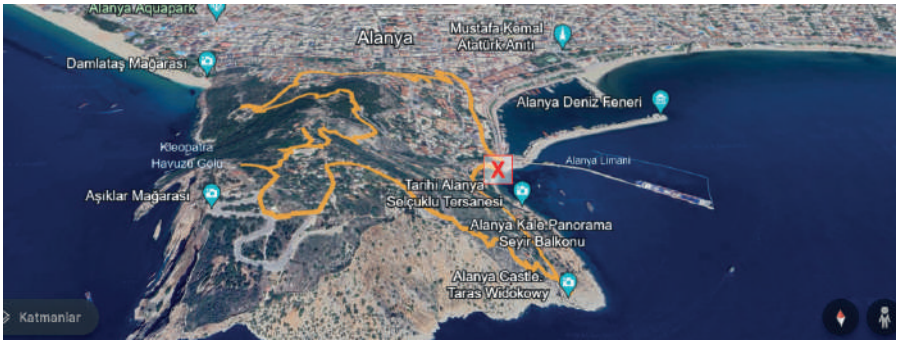

Figure 9. The Route

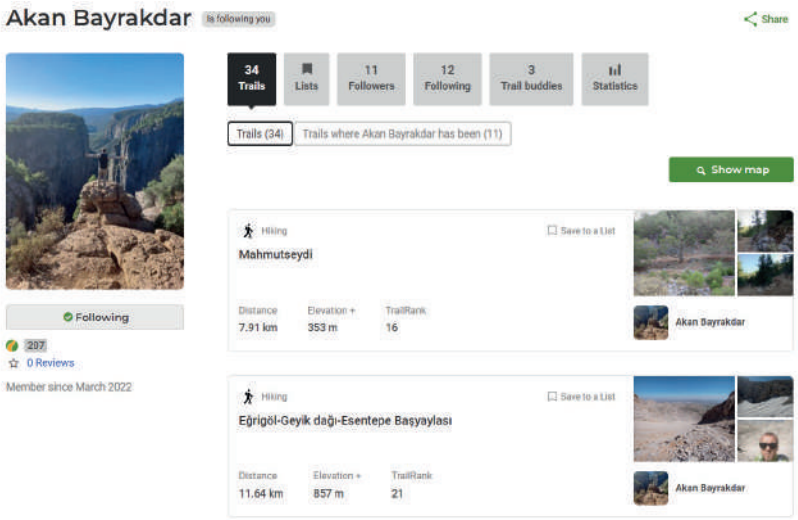

Figure 10. Following Trails of Others

There are other devices that recreational outdoor participants use. For example, recreational cyclists and runners use smart watches to assess their development during the exercise. As outdoor activities, running and cycling are considered as endurance requiring sports. So to follow and trying to enhance performance, recreational runners and cyclists use smart watches. In a study carried out on recreational and competitive runners, it was found that these individuals generally use more than one type of smart devices. The most used type of smart devices is smart sport watches. Also, recreational runners use their smart phones and apps as well as wristbands more commonly than competitive runners (Clermont, Duffett-Leger, Hettinga & Ferber, 2020). In the literature, it is also claimed that most runners consider these devices as virtual coaches that assist them during the activity (Scataglini, Cools, Neyrinck & Verwulgen, 2021). In another study, it was stated that almost all app and device using runners monitored their distance, time, and speed during running (Jansen, Walravens, Thibaut & Scheerder, 2020). As for the recreational mountain bikers, new research proposes ideas related to risk and injury prevention (Langer, Dietz & Butz, 2021); therefore, in the near future, devices and apps can be developed to prevent the participants from getting injured or choose the risk they want to take. Some research, on the other hand, approach the subject from another angle. Wu et.al (2020), proposed to develop a new app for the cyclists to assess all the data of the individuals all day including during exercise and create new exercise prescriptions (see Figure 11).

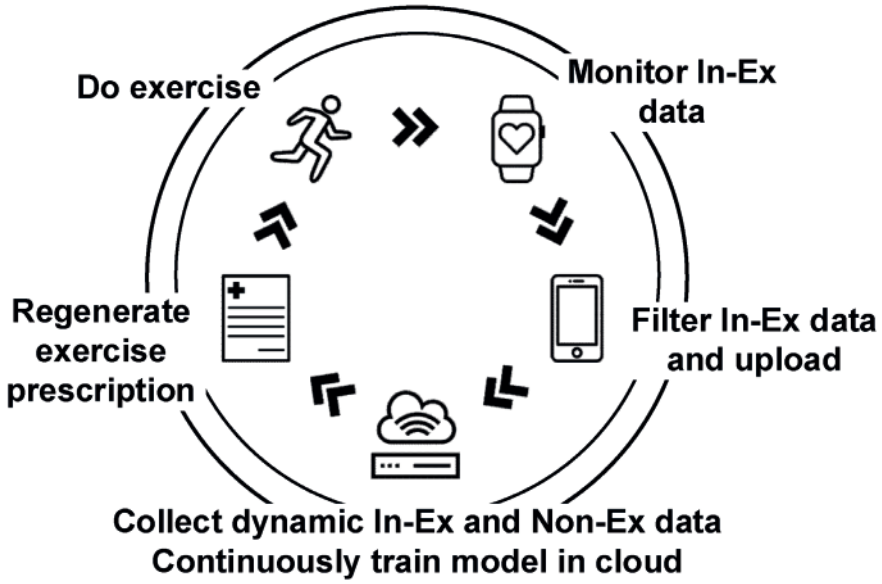

Figure 11. The various parts of the closed loop containing the prediction model

Technology use in outdoor recreation as a simulation

The technological developments can be used as a simulation in the outdoor recreation. Virtual reality (VR) has become more and more popular throughout the years, and individuals became addicted to the experience of the VR. The ancestors of the contemporary VR are Sensorama which is the Morton Heilig's system where users could ride a motorbike in New York and Flight Simulators originally designed for military services (Gigante, 1993). Flight simulators allowed scientist to understand the technical requirements underlying VR. Today VR is in our living rooms. Individuals all around the world, horror games, war games, play tennis or do archery and even dance on the same day thanks to the VR googles. In the literature, it is stated that virtual reality can initially contribute to the individuals who cannot participate in the outdoor recreational activities directly (Winter, Selin, Cerveny & Bricker, 2019). VR technology is stated to facilitate a reconnection with the natural recreational environment (Scarles et.al., 2020). Also, there are studies indicating that VR technology can be as effective as actual nature in promoting ecological behavior meaning individuals using VR to experience nature and outdoor also gain awareness, and act on it (Deringer & Hanley, 2021). In another study, the researchers found that six minutes of nature exposure in mobile VR headsets produced similar effects as 6 min of outdoor nature exposure (Browning et.al., 2020).

VR can also be used in the outdoor education. As it was used in flight experiences, VR use in outdoor education can help the participants get used to the threats and opportunities in the outdoor environment. One example is the study carried out the measure the leadership development of students taking the outdoor education lessons. The study revealed that adding virtual reality to exploratory education proved that the experience allowed students to generate learning attitudes and change their behavior to the expected level more easily (Lin, Wang, Kuo & Luo, 2017). When the outdoor education is considered, another significant thing to consider is Mobile Augmented Reality (MAR) which utilize mobile devices to deliver digital learning resources that are triggered by GPS location by QR codes (Ryokai & Agogino, 2013). The literature indicates that MAR use for outdoor education is burden-free and greatly needful and helpful tool for education (Kuo, Lin, Shen & Jeng, 2004; Cuthbertson, Socha & Potter, 2004). However, it is suggested to be used with the traditional education methods (Joan, 2015).

Conclusion

As humans, we are very lucky to have seen the technology enhancing to the level it is now. The outdoor recreationists are even luckier to have the devices and applications to be used during their activities. This chapter included developed and developing technologies that are used and can be used in the outdoor environments and/or in the environments which stimulate the participants' brains to give the same reaction as outdoor experiences. Technology use in outdoor recreation has been discussed under four terms as motivator, comfort, performance auditing and simulation. These are each and all reasons why individuals choose to use and make use of the technology involved in outdoor recreation. Nevertheless, whatever the reason, individuals should continue to use the technology in order to further develop it with their feedback and to create a better environmentally friendly next generation. When more individuals use these devices and apps, more individuals will be out in the nature which can raise awareness related to nature and natural environments to be taught to the next generation. Since the climate change and air, water and environmental pollution have become a threat to all of us, nature-conscious generations can take their step more seriously and carefully. Also, making use of these technologies, individuals can live their lives more healthily which reduces the time and money spent on the public health. Lastly, individuals can enjoy the views of nature and appreciate it more when they continue to participate in the outdoor recreation activities.

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