Journal of Physical Education and Sport ® (JPES), Vol. 24 (issue 1), Art 6, pp. 44 - 52, January 2024
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

A comprehensive overview of artificial intelligence applications in basketball

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Published online: January 31, 2024
(Accepted for publication January 15, 2024)
DOI:10.7752/jpes.2024.01006

Abstract:
The sports industry is progressively embracing technological advancements, and artificial intelligence stands out as a prominent innovation. Basketball in particular, has captured the interest of the real-time analytics and data science community. With the development, deployment, and experience of AI models by both viewers and players, it is crucial to provide a comprehensive summary of AI applications in basketball. This review is performed based on literature sourced from Web of Science and Dimensions databases, where articles were thoroughly examined to identify AI use cases. The study was backed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework and furthermore utilized computational literature review as well as bibliometric analysis techniques for knowledge extraction purposes. Our results revealed that the area of sports analytics is gaining momentum and AI in the basketball world has more adoption in China, USA, Australia, Canada, Italy and Spain from a research perspective. Our study offers contributions to theory and practice in the sports science and applied AI domains.
Key Words: - **Basketball, Artificial Intelligence, Machine Learning, Sports, Data-Driven Decision-Making**

Introduction

Today, big data, artificial intelligence (AI), and machine learning (ML) are some of the buzzwords one will encounter in business, healthcare, education, governance, and entertainment. Different domains have experienced and continue to experience varying shares in the diffusion of these modern technological innovations. Simovic et al. (2019) indicated that the famous sports journalist (Henry Chadwicks), was the pioneer in the realisation of the need to analyse player performance as early as 1858. Thus, for baseball matches (Simovic et al., 2019), this made him devise the "box score" which was meant for gathering data.

We are currently in the era where data is being adopted in supporting decision making in certain aspects of sports such as athlete management, training and performance assessment, refereeing, and coaching strategy. Thus one can notice this trend in both contact sports and non-contact sports. Research has also pointed out that today, coaches and athletes recognize that quality data is of high value and can be used to support decision making (objective) on certain aspects of training and performance (Passfield & Hopker, 2017). This fusion of sports and analytics has its educational benefits which researchers purported as follows: students who may not find themselves traditionally engaged in STEM (Science, Technology, Engineering, and Mathematics) will potentially be motivated (intrinsically) to adopt STEM concepts as a medium for basketball training. The same can be said for individuals not trained in traditional STEM or even sports fields who are taking up careers in sports analytics by combining their interest in sports with the desire to apply analytical techniques to support the decision making process within the sport of their interest (Drazan et al., 2017).

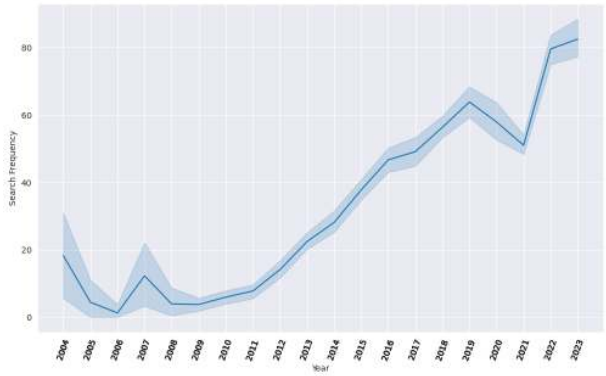

Figure 1. Sports Analytics (Worldwide Google Trends)

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Figure 1 highlights the trend with regards to the term "sports analytics" from Google Trends and one can observe the growth rate which is correspondent with the increasing interest in sports analytics; whether career-wise or research-oriented (Baumer et al., 2023; Brefeld & Zimmermann, 2017; Pu et al., 2024; Singh, 2020).

In their review, methods used by researchers in sports data analytics include linear regression, logistic regression, support vector machines (SVM), Naive Bayes, Boosted Decision Trees, and Artificial Neural Networks in the PGA Tour, FINA World Aquatics Championships, Dutch Football League, Iran Pro League (IPL), German League (Bundesliga), National Basketball Association (NBA), Australian Football League (AFL) and National Rugby League (NRL) (Safari et al., 2022).

One may assume that pundits, experts, coaches and basketball players are in support of the diffusion of analytics and AI in the sport, but there are opposing views. Dawson (2023) highlights the perspective of critics of analytics in basketball. The study brought to light a relevant point that analytics in the sport has created a new iron cage where there is the dehumanization of statistics, in place of the pure emotion that surrounds the game as well as efficiency being valorized (Dawson, 2023). Regardless of the critiques, the role of AI in the sport cannot be undermined. Hence, we delve into providing a snapshot of research on the domain of discourse. The goal of this study is to highlight the research trajectory and state of the art of AI in basketball. As such we answer the following research questions: (1) What is the state and trajectory of research (from a bibliometric perspective) with regards to AI in basketball?; (2) What are the common themes that are covered in AI and basketball research? The subsequent sections seek to answer the research questions.

AI Diffusion and its Role in Basketball

Just as AI has found its way into numerous business processes, and facets of everyday life, the sports world is no stranger to this innovative revolution. The game of basketball which is a contact sport has had its fair share of criticism with regards to fair play, cheating and wrong referee calls as such some experts believe the introduction of AI should curb down such wrongful judgments and eliminate any form of unfairness so as to improve the sport's credibility and overall enjoyment. AI technology, despite ongoing research and adoption, has been reported to have significant effects on improving basketball players training which will be of help to coaches to enable them formulate game strategies, and curb injuries (Li & Xu, 2021). AI has gradually made its way into the sport and can be seen in player performance analysis, injury prevention, game strategy, and refereeing. Simultaneously, basketball has seen a rapid growth in the use of AI where people have developed a variety of ways to improve the game. Some of those ways include Player Performance Analysis to analyze player's game records, identify areas of improvement and to develop personalized training programs.

A study pointed out the fact that since basketball is one of Lithuania's most popular sports, many teams have integrated some form of analytics into the management of the sport and it has been viewed within a positive light with a huge future potential (Demenius & Kreivytė, 2017). AI is being used to track player movements and to identify potential injuries before they happen by learning player actions. Researchers proposed a machine-learning approach to measure the anterior cruciate ligament (ACL) injury risk in female basketball players and they evaluate the proposed method on a dataset of female basketball players while achieving an accuracy of 80% in predicting the risk of ACL injury (Taborri et al., 2021).

Review Paper Context	**Articles**
As reported by researchers, due to injuries, basketball games missed led to a loss in revenue of USD 344 million in 2015. They indicated that AI is capable of predicting the risk of injuries (some) during the training phase. The survey also indicated that a study also delved into the improvement of basketball players' shooting technique.	(Chidambaram et al., 2022)
This study highlighted the following with respect to AI within basketball players - heart defect detection; technical, physical, and tactical analysis; injury risk assessment with AI; and prediction algorithms for the improvement of athletic performance of basketball players.	(Claudino et al., 2019)
This study highlighted the computer-vision (CV) methods implemented in basketball: player action recognition; future/basketball trajectory prediction; line-up performance prediction from on-field situation analysis; multiple player tracking; real-time referee signal recognition; event classification (player pose and location detection); defensive strategy (switch and trap) prediction; behaviour analysis of players; and three-pointer prediction.	(Naik et al., 2022)
The study summarised the following applications: scoring prediction; classification of screen-play; prediction of the individual to obtain the ball during rebound.	(Fujii, 2021)

This study summarised a few applications of only deep neural network models in basketball - Realistic defensive plays generation based on ball and offensive term movement (Generative Adversarial Networks (GAN)); Offensive tactic simulation sketched by coaches (GAN); Three-point shot Prediction (Recurrent Neural Networks (RNN)); Player's movement semantic (Auto-Encoders (AE)); Complex multi-agent behaviour Modelling (Variational RNN); Shot prediction (Convolutional Neural Network + feedforward neural network (FNN)); double team - when and where? (Reinforcement learning); Action recognition (Convolutional Neural Network (CNN) + Densely-connected Bi-directional LSTM); with majority using NBA SportVu, STATS SportVu, UCF101 and Signality datasets.	(Mgaya et al., 2021)
This study explored the context of Human Activity Recognition (HAR) with respect to basketball such as driving, passing and dribbling the ball. Studies also included: group activity recognition (score/not score); multi-player activity detection (defence, offence or time-out); pose estimation (actions include - no_action, walk, run, dribble, throw, and receive_ball).	(Host & Ivašić-Kos, 2022)

Table 1. Summary of Review Paper Findings

Table 1 highlights a summary of findings from all the review papers. The reviews conducted by previous studies were context-specific within the sport, but in our research we focus on the bibliometric and generalized overview of the applications of AI in basketball. The next section answers the research questions by outlining the data and knowledge extraction methodology adopted for the study.

Data and Methods

For the purpose of our study, data was gathered from Scopus and Dimensions.ai research databases, as it is known to be credible resources. The search strategy was composed of the following keywords: ("basketball") AND ("artificial intelligence" OR "machine learning" OR "deep learning" OR "reinforcement learning"). A total of 678 articles were obtained from the combined literature search. The literature search strategy and methodology is backed by the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) framework (Liberati et al., 2009). Records were merged and screened to ensure they did not focus on other sports like football, soccer, or tennis. The inclusion criteria for selecting the documents to be utilized for the study included: all scientific publications that meet the topic's framework, articles in English language, sources limited to journals, conference proceedings and book chapters. With respect to the exclusion criteria, articles that were non-English, preprints, or had no bearing on the theme in focus were eliminated upon manual inspection by the authors. Thus a resultant number of 383 scientific publications were obtained. Figure 2 highlights the entire aforementioned workflow.

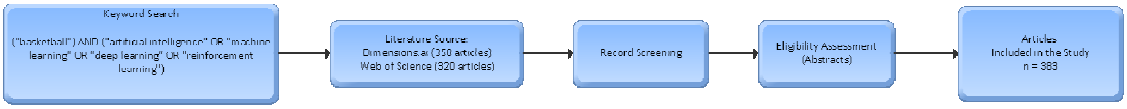

Figure 2. Literature Search Workflow

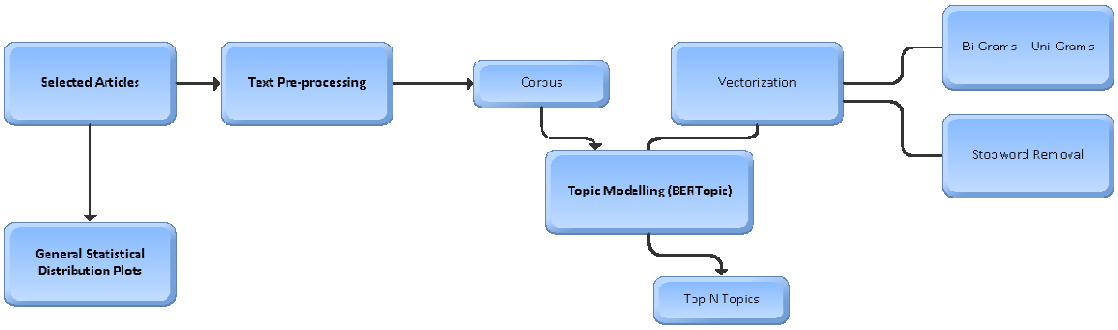

Figure 3. Knowledge Extraction Workflow

To further delve into the aims of the study, we utilized computational literature review (CLR) techniques which entailed the adoption of topic modelling as well as bibliometric analysis to extract valuable knowledge. CLR has been adopted by previous studies to explore research on AI in management; the state of AI in organization and managerial research; as well as the state of AI in the coaching domain (Arsenyan & Piepenbrink, 2023; Hinkelmann, 2022; Smacchia & Za, 2022). As such, we determined CLR to be an efficient approach for knowledge extraction (Figure 3 highlights the workflow). We utilized two different tools, the first

being the Bibliometrix package from the R programming language for extracting bibliometric results and the BERTopic package and model from the Python language (Aria & Cuccurullo, 2017; Grootendorst, 2022). BERTopic leverages Google's BERT embedding and a cluster-based term frequency - inverse document frequency (c-TF-IDF) to create dense clusters for formulating topics that are easily interpretable while ensuring the preservation of relevant words in topic descriptions (Samsir et al., 2023). BERTopic is preferred for NLP tasks due to its contextual information capture ability, improved performance, and multilingual support (Samsir et al., 2023). BERTopic has been adopted by medical research for thematic trend analysis as well as in sports management to model the structure of the research domain (dos Santos et al., 2023; Guizzardi et al., 2023). As such, we deemed BERTopic as an efficient tool to conduct topic modelling (an unsupervised machine learning technique used to discover latent terms (topics) from large collections of documents (corpus of text) (Blei et al., 2003; Khan & Ali, 2020)). In our case, the abstracts were treated as the documents for conducting topic modelling.

Results and Discussion

With respect to basketball and artificial intelligence research, based on the 383 articles subset from the data collated from Scopus, the annual research growth (as seen in Figure 2) in the intersection of these two fields is pegged at 16.1%. Articles span from 1999 to 2023 consisting of 282 sources, authored by 1082 researchers (with the rate of international collaboration/co-authorship accounting for 14.36%). The top 10 most relevant institutions that contributed mostly to research on AI and basketball include: Albert Einstein College of Medicine (USA); University of Calgary (Canada); Fu Jen Catholic University (Taiwan); Beijing Sport University (China); Northeastern University at Qinhuangdao (China); The University North (Sveučilište Sjever) (Croatia); Yangzhou University (China); Zhejiang University (China); City University of Hong Kong (Hong Kong); Nanjing University of Information Science & Technology (China). Figure 4 illustrates the distribution of research publication on AI in basketball research over time from 1999 to 2023. A sharp growth in AI research with respect to basketball can be observed in 2016 and beyond; this can be linked to the development of deep learning.

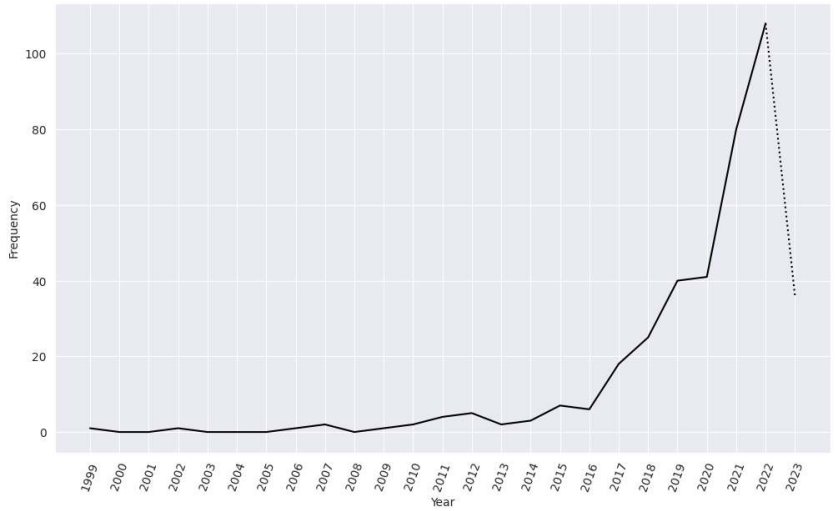

Figure 4. Distribution of Annual Research Production

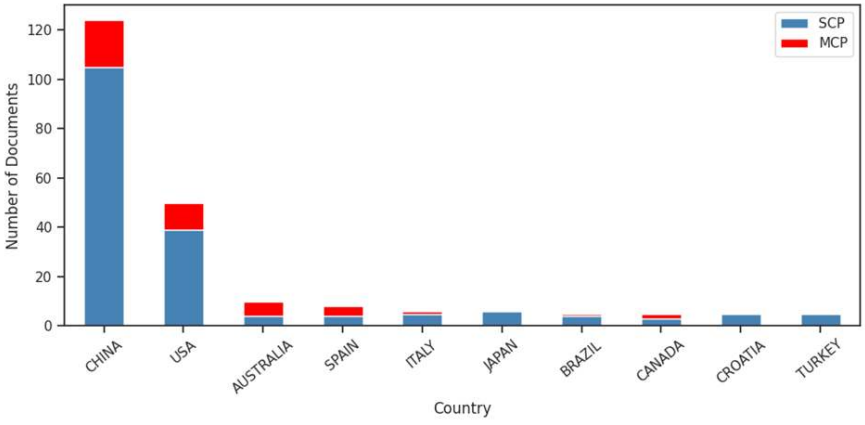

Figure 5. Distribution of Corresponding Author's Country

Figure 5 highlights country-specific metrics with respect to the corresponding authors. The graph highlights the single country publications (SCP) and the multiple country publications (MCP) of researchers. MCP is indicative of the level of international collaboration. Thus, one can observe that there is a high level of collaboration by researchers from China, USA, Australia, Spain, Canada, and Italy. These observations can be linked to the growth of the game and profession of basketball in the NBA (National Basketball Association) - USA and Canada, CBA (Chinese Basketball Association), NBL (National Basketball League) - Australia, and Euroleague.

Use-Case	**AI Algorithm and Architecture**	**Dataset**	**Research Paper**
This study developed a deep learning based intelligent basketball arena system to automatically broadcast the basketball match	Single Frame based CNN, Optical Flow, 3-D CNN, BEI + Pyramid HOG + SVM, and proposed model is BEI+CNN	20 hours of real-world match videos	(Li & Xu, 2021)
The research paper proposed a deep learning model, called METIC (Multiple bidirectional Encoder Transformers for Injury Classification), to predict future injuries based on past injuries, game activity, and player statistics. The model was trained on the longitudinal data of NBA player injuries.	The research paper compared the performance of the METIC model to other traditional machine learning approaches. The METIC model can be used by practitioners to improve athlete management and reduce injury incidence.	Publicly available longitudinal NBA player injury data, encompassing player demographics, playing history, injury history, and game statistics.	(Cohan et al., 2021)
Basketball shooting action recognition through image feature extraction and machine learning, involving feature extraction of player, ball, and hoop positions and orientations, followed by training a machine learning model for classification.	The scale-invariant feature transform (SIFT) algorithm is a promising approach for basketball shooting action recognition. The method can be used to improve the efficiency and accuracy of basketball shooting analysis.	The research paper employed top-down view image data of basketball shooting actions, incorporating details on player and ball positions, as well as hoop orientation.	(Ji et al., 2021)
The proposed deep learning algorithm can be used to develop wearable devices that can be used to track human activities. The devices can be used to monitor fitness, improve athletic performance, and track health conditions.	The research paper compared the performance of the proposed algorithm to other HAR algorithms that use wearable devices. The proposed algorithm achieved higher accuracy than the other algorithms.	The research paper used sensor data collected from wearable devices. The sensors included an accelerometer, a gyroscope, and a magnetometer. The sensor data was collected at a frequency of 50 Hz.	(Jiang & Zhang, 2023)
The proposed deep learning approach can be used to develop basketball video analysis systems. These systems can be used to track basketball players, analyse basketball plays, and generate statistics about basketball games.	The proposed approach uses a two-stage detection framework. The first stage uses a RPN to generate candidate bounding boxes for basketball players. The second stage uses a Fast R-CNN to classify the candidate bounding boxes as basketball players or not.	The research paper used basketball videos. The videos were collected from publicly available sources. The videos included both indoor and outdoor basketball games.	(Ji et al., 2021)
The proposed method enables efficient and accurate analysis of technical features in basketball videos through automated detection and tracking of player movements. Coaches and analysts may use these insights to improve team strategy and evaluate player performance.	Transfer learning technique based on pre-trained CNN architectures is employed to achieve robust feature extraction and identification tasks.	Basketball video recordings	(Chen & Wang, 2020)

Table 2. Examples of AI models in Basketball

Table 2 summarizes an overview of AI in basketball use cases, the datasets and algorithms as well as the neural network architectures (if existent) used. The results presented provide a snapshot of research on AI in basketball as well as information for researchers to develop future trajectories based on the present state of the art.

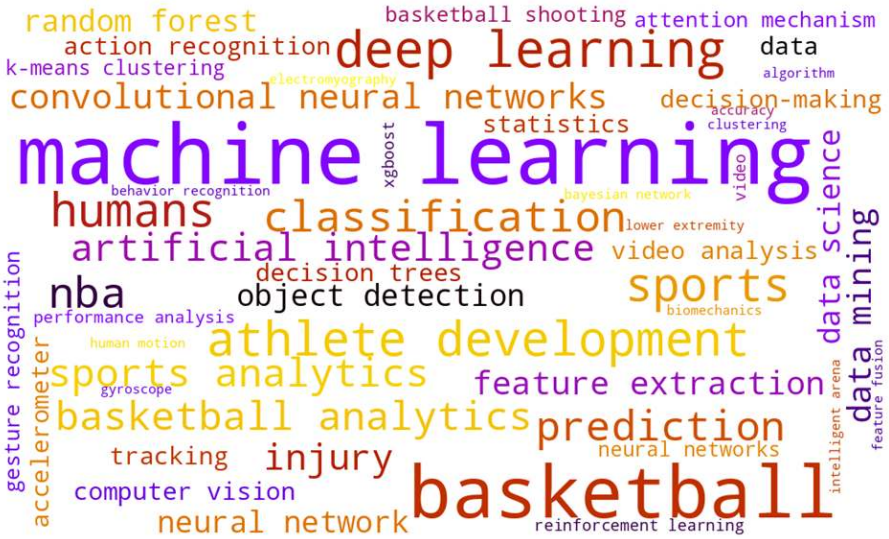

Figure 6. Top 50 Salient Terms (from Authors' Keywords)

Figure 6 represents a word cloud visualization that consists of the top 50 salient terms (uni-grams and bi-grams) obtained from the abstracts used in this study. In our research, we ensured that the dataset underwent pre-processing to clean any irrelevant words or tokens (reference figure 3). Finally, we obtained the top 50 terms from the dataset of literature on AI and basketball. Themes that cut across AI and machine learning can be observed, computer vision, tracking, object detection, video analysis, action mechanism, action recognition, behavior recognition, and gesture recognition can be observed. These provide evidence to the fact that basketball and AI research primarily relies on video data to produce models for prediction purposes. Other noticeable terms include player development, injury, lower extremity, and basketball analytics which focus on the individual player and measuring certain vital statistics to improve the player's game. Aside from focusing on the player, we observe the interest in a term such as gyroscope which has to do with the inclusion of such microcontroller devices in basketballs for measuring the dynamics of the ball.

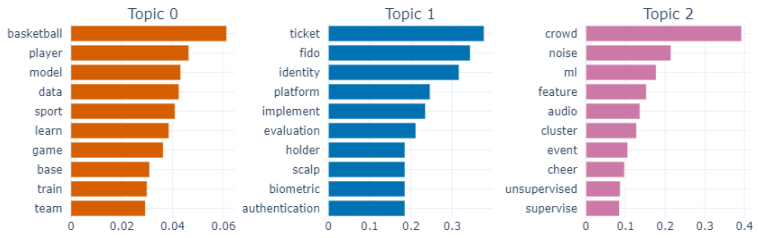

Figure 7. Topic Modelling Results

Figure 7 highlights the distribution of themes across three (3) topics. We obtained 3 due to the fact that the size of the dataset. To further make sense of the topics, we deduce a theme from the list of terms and summarise the results as follows:

1. Topic 0 - Leveraging Data-Driven Models to Enhance Basketball Player Training and Team Performance. Applying AI techniques to data from basketball games to make informed decisions covers numerous aspects of the sport. Studies have looked at ball trajectory classification; game outcome prediction; AI assistants for supporting training sessions (Alonso & Babac, 2022; Yu et al., 2022). The goal of such insights is to support coaches and trainers as well as guide experts into providing the optimal care.
2. Topic 1: Optimising Game Ticket Security and User Identity Verification through FIDO Technology and Biometric Authentication. The game of basketball is also a business and as such ticket validation and security is important to keep clubs running. To curb issues related with ticket scams, biometric

models have been proposed by researchers - one of such is the fast identity online technology (FIDO) (Lio & Okada, 2020). In light of the value of such biometric data, it is important that researchers also consider data regulation and take necessary privacy measures to secure such sensitive data (Najjar, 2023).

3. Topic 2: ML for Crowd Audio Feature Extraction and Event Clustering. Aside from focusing on the game itself, research has also focused on the spectators. Research has identified that home game performance is synonymous with spectator/crowd sentiments (Gong et al., 2021). Thus, it is pertinent that research also focuses on spectators to extract knowledge which can aid in decision making in crowd management during games. A study built ML models to classify crowd responses during games (Butler et al., 2018).

We believe the topics revealed can provide guidance to researchers and data science enthusiasts to channel their expertise into the sports analytics industry to push it forward. With respect to the future of AI in basketball, experts should be able to transfer knowledge from the generative AI revolution into the basketball sphere. Application of models based on diffusion models, variational autoencoders, GANs and Transformers can assist in generating realistic and efficient basketball player trajectories using diffusion-based planning, or a probabilistic diffusion model for entire game-play generation. These models could generate realistic and diverse plays that are tailored to play strengths and weaknesses of the team and its prospective opponent. In doing so, there will be support for training, coaching, player welfare and managerial decision-making in basketball.

Conclusions

The diffusion of AI in all aspects of life and business is without a doubt an essential phenomena that cannot be overlooked. Basketball has not been left behind, as such our research was aimed at exploring the use of AI in basketball by computationally summarising the trajectory, tools and datasets utilised by other research. This article presented a comprehensive overview on research with respect to AI applications in basketball. In addition to that we provided evidence of the state-of-the-art as well as relevant information for future studies to build upon. Presently, we observed that, the application of AI in basketball is centered around professional games. This study contributes to theory by contributing to the literature on applied AI - primarily in sports sciences and provides an overview for researchers to build their studies on. Practical implications of the study are evident in the exposure to concepts that can be explored by startups to venture into sports analytics by leveraging on existing models to apply these in all countries irrelevant of the level of economic livelihood. Models used in other contact sports can be adopted and retrained by experts to be applied in the basketball context. Future research will consider expanding the data source to articles which are not indexed in Web of Science or Dimensions databases. In addition, it is recommended that researchers study the applications of explainable AI - a modern paradigm - into ML/AI models in basketball. Finally, we recommend future research to explore multi-modal training of models where multiple forms of data can be aggregated and trained before deploying into real-time practical scenarios.

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

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