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Performance analysis in sport and soccer: Past, present and future – narrative review

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ABSTRACT

As performance analysis (PA) in sport and soccer has developed, numerous methods of analysis are available to provide objective video and data insights on performances. The purpose of this narrative review is to discuss PA in sport and soccer, critically appraise past and present PA techniques and preview the future of PA to enhance knowledge and inform PA practices. The methodology featured a literature review of key research papers within the areas of manual and computerised notational analysis, manual and computerised time motion analysis, wearable technology, stadium infrastructure, artificial intelligence and ethical considerations of PA. The findings of this review determined there are varied methods of PA available to practitioners to conduct technical, tactical and physical analysis within sport and soccer. Each technique features varied workflows and budget requirements which influence process advantages, disadvantages and accessibility. The evaluation of methods allowed the review to determine a decision-making matrix that can be used by practitioners to identify the most applicable PA procedures related to their resources, infrastructure and analytical aims. Alongside the decision-making matrix, the review also found that there are key ethical considerations regarding the delivery of PA insights. Given the wide array of PA tools available, and artificial intelligence influences likely to increase in the future, practitioners need to carefully consider what analysis is conducted, when insights are delivered and how information is provided to ensure effective, ethical practices.

Contribution/Originality: This review discusses the evolution of performance analysis in sport and soccer. Previous reviews focus on specific areas of performance analysis. In contrast, this review utilises a holistic approach, inclusive of varied analytical methods, and produces a decision-making matrix to inform the most accessible and effective analysis strategy for practitioners.

1. INTRODUCTION

Performance analysis (PA) in sport features the objective measurement of technical, tactical, physical, sociological and psychological performance through quantitative (I.e., number of goals scored), and qualitative (I.e., video footage) data. The aim of PA is to enhance knowledge of coach or athlete performance and inform decision-making of key sports stakeholders, for example, managers, sporting directors, heads of recruitment, coaches and athletes. Enhanced decision making aims to improve athletic execution and outcome (Hughes & Bartlett, 2015; Hughes, Franks, & Dancs, 2019; O'Donoghue, 2014). The theoretical underpinning of PA is based on sub-optimal recall created by subjective observations from sports practitioners, for example, coaches and athletes (Carling,

Williams, & Reilly, 2007; Hughes & Bartlett, 2015) with numerous studies determining that accurate sporting event recall can be as low as 30% (I.e., potentially 7 out of 10 recall attempts being inaccurate) (Franks & Miller, 1986, 1991; Laird & Waters, 2008; Nicholls & Worsfold, 2016). Given the importance of accurate decision-making pre, during and post competition, clear appraisal of performance is vital to inform effective decision-making in performance, talent identification, talent development and other contexts (Barron, Ball, Robins, & Sunderland, 2018; Sampaio & Maçãs, 2012; Wright, Atkins, & Jones, 2012). In addition to immediate coach recall, there is also a time-recall relationship present, meaning, regardless of the recall success, recall will deteriorate over time (Smith, Rands, Bateman, & Francis, 2022). The advancements of audio and visual technology within sport has permitted performance analysts to implement the use of video and data evidence which allows coaches, athletes and others the ability to utilise accurate, objective information to inform decision-making based on live performances, previously observed performances, or, via video without needing to initially observe live performances or recall information (Groom, Cushion, & Nelson, 2011; Hoenig et al., 2023).

Association football (I.e. soccer) has adopted PA practices for more than 70 years (Pollard, 2002) with consistent developments surrounding the discipline and applied practice of PA alongside technology (Mackenzie & Cushion, 2013a). Within soccer, technical, tactical and physical components of performance are most commonly analysed due to the objective nature of technical (I.e. passing, shooting and dribbling), tactical (I.e. formations, team height, depth and width) and physical (I.e. distance covered, sprint information) actions (Arjol-Serrano et al., 2021; Díez et al., 2021; Errekagorri, Castellano, Echeazarra, & Lago-Peñas, 2020; Filetti, Ruscello, D'Ottavio, & Fanelli, 2017; Forcher et al., 2023; García-Calvo et al., 2021). Psychological (I.e. decision making, composure) and social (I.e. team work, communication) behaviour can be included in PA, but such performance components are more difficult to analyse in isolation, for example, determining thought processes, arousal levels and team cohesion is difficult to measure within performances via common PA practices, though psychological and social behaviour within technical, tactical or physical actions can be analysed more easily, for example, passing network analysis can be used as a proxy for team cohesion or collaboration, and wearable technology can determine running statistics that could be linked to athlete effort (Forsman, Blomqvist, Davids, Liukkonen, & Konttinen, 2016; García-Calvo et al., 2021; Ponce-Bordón, García-Calvo, López-Gajardo, Díaz-García, & González-Ponce, 2022; Towlson, Cope, Perry, Court, & Levett, 2019). Within PA, the psychological and social impact of analysis feedback from performance staff to athletes is also relevant (Groom et al., 2011; McKenna, Cowan, Stevenson, & Baker, 2018; Middlemas & Harwood, 2018; Pain & Harwood, 2007; Reeves & Roberts, 2013; Wright, Carling, Lawlor, & Collins, 2016).

Due to the development of PA in sport and soccer in terms of popularity, procedures and technology systems available to capture performance, it appears to be a worthwhile time to review how PA has developed by investigating its origin, how PA practices operate today and key considerations for future PA development and application from an academic and applied viewpoint. Numerous PA based review papers have been published which provide effective discussion topics on the past, present and future, or more specific elements of PA, sport and soccer (Bădescu, Zaharie, Stoian, Bădescu, & Stanciu, 2022; Lord, Pyne, Welvaert, & Mara, 2020; Mackenzie & Cushion, 2013b; McGarry, 2009; Sarmento et al., 2014; Torres-Ronda, Beanland, Whitehead, Sweeting, & Clubb, 2022). While effective, these reviews can be built upon in terms of a contemporary reflection of the PA field and renewed future recommendations. Therefore, the aims of this narrative review are to; 1) provide a concise overview of the literature (to date) relating to the evolution of PA technology and research within soccer; 2) To identify the current benefits and limitations of PA technologies within soccer; 3) To propose applied and academic PA considerations which could develop knowledge and performance within current or future practice.

2. PAST

Within sport, the earliest report of PA techniques occurred in baseball, with box scores objectively quantifying the performances of both teams (McKenna et al., 2018; Sullivan, 1995). In addition to baseball, racket sports such as

tennis have also adopted notational analysis to analyse technical actions such as serving performance, winners and unforced errors, prior to the use of PA within soccer (Carling et al., 2007). These examples outline that PA can be applied to ball and bat, racket and invasion sports (Hughes & Bartlett, 2002). The application of PA is well suited to sports with closed event loops in which a set phase of play occurs prior to a stop in play and a repeat of the executed events, for example, a pitch and attempted hit in baseball. Once the ball is safely with the fielding team, the batter is out or the ball is hit out of play for a home run, the play stops, usually after fewer than 10 seconds, and the process repeats with both teams having bouts of batting and fielding until the end of the match (Hughes & Bartlett, 2002; Liang, Chu, Kuo, Wu, & Cheng, 2005). Invasion sports, and soccer in particular, have proven more difficult to analyse. When the game is stopped or the ball goes out of play, numerous set piece events, for example, kick offs, freekicks, corners, throw-ins and penalties can occur in a varied order. When the game is in flow and the ball is in play, more open, variable and complex events involving numerous players then occur. In invasion sports, both teams attempt to dictate the events that occur and their order, rather than set events occurring repeatedly as in the baseball example (Grehaigne, Bouthier, & David, 1997; Hewitt, Greenham, & Norton, 2016; Lemmink & Frencken, 2013).

Regarding technical and tactical performance criteria in soccer, Charles Reep has been credited with the earliest notational analysis system, created in 1950. The system involved recording the frequency of performance indicators (PIs), or key performance indicators (KPIs), known as action variables that aim to define or measure performance (I.e., goals and passing sequences) that occurred within a soccer match (Pollard, 2002). Reep's notational analysis processes were completed using paper and a pencil to make a hand-based recording of events, given the lack of computerised, camera or video-based technology available in the 1950's (James, 2006a). Reep's findings were revolutionary, with objective information being utilised to enhance knowledge, inform decision making regarding tactical changes and support improved athletic performance. Reep's work, therefore, provided contrast to the subjective judgements that had previously dominated decision making within the game (Larson, 2001; Pollard, 2002). Reep mainly focussed upon key actions such as passes, shots and goals, amongst contextual factors such as the score line and location on the pitch that events occur. From a technical and tactical point of view, the analysis findings suggested that 80% of goals were scored from three passes or less, with 50% of goals coming from possession being won in the final quarter of the pitch (Reep & Benjamin, 1968). These findings will be discussed later in the review regarding more recent analytical findings.

A key drawback to Reep, and other early performance analysts work, however, was the engagement phenomenon, with many self or peer-declared soccer experts being unwilling to listen, interact or utilise from PA findings (Pollard, 2019). Fittingly, the engagement phenomenon is one that has been intertwined with PA alongside playing and coaching disciplines throughout its history, with coaches highlighting numerous challenges regarding the application of PA (Barker-Ruchti, Svensson, Svensson, & Fransson, 2021; Groom et al., 2011; Middlemas & Harwood, 2018; Wright et al., 2012), this will be discussed in more detail later in the review. Despite a lack of unanimous engagement with Reep and others' ideas, Reep's work did resonate with some, with teams such as Swindon Town, Wolverhampton Wanderers and Watford FC, adopting a more direct approach, meaning teams took fewer passes of increased length to try and reach a viable shooting position close to the opponent's goal as quickly as possible (Pollard, 2019). This direct play in matches, and likely within training, highlights the practical application of PA within soccer and the initial stages of team profiling based on playing style (Larson, 2001). Despite success with the teams he worked with, though such success cannot be solely attributed to Reep's work due to the multifaceted nature of soccer, drawbacks were present in the methodology of Reep's work and the application of his findings and suggestions (Pollard, 2019). It could be argued that such criticism is present due to the pioneering initial attempt from Reep, with his work forming the foundation for future attempts. Many of the authors criticising the method claimed that Reep's analysis was too simplistic, flawed or misleading, although Pollard (Pollard, 2019), argues that despite numerous challenges, no paper has provided enough evidence or

effective criticisms to suggest that the direct style of play Reep suggested was not the superior plan. That said, Pollard (Pollard, 2019) acknowledges that within Reep's possession-based analysis, additional context, situational factors and match events were missing. This uncovers a drawback that could be linked with the difficulty of live hand notation within matches, prior to consistent access to video footage to review the analysis. Without the aid of video-based analysis, analysts were limited in how many match factors or PIs they could analyse live, with no video to add extra measurements or perform reliability testing (Hughes, 2003).

Adding to that, the lack of video-based analysis also limited the feedback methods of early analysts, without the ability to deliver findings to athletes and coaches via video, telestration and computerised data visualisations which can be used to effectively educate and motivate (Hughes, 2003). Whichever side of the fence an academic or applied practitioner sits with Reep's work, his work was the catalyst for soccer to become analysed, measured and objective to support subjective thought regarding tactics, strategies and technical execution (James, 2015; Pollard & Reep, 1997). Technology and development of the PA discipline have been able to contribute to analytical development from Reep's foundations (James, 2015; Pollard & Reep, 1997). Whilst technical and tactical analysis has been present in sport, and more specifically soccer as discussed, the origins of physical or movement analysis is also worth discussion.

Within sport, physical movement is required to engage in technical execution, for example, a baseball swing, a hurdle race jump or shot in soccer, providing the foundation for physical analysis to investigate how resultant technical performance is executed via knowledge of performance chains contributing to such execution (Cook, Burton, & Hoogenboom, 2006; Hughes, 2003; Knudson, 2007). Without the use of technology, analysts and sport scientists have been able to develop hand notational systems to analyse movements that are linked to technical analysis, for example, stroke type and court positioning in squash (Sanderson & May, 1977) or Reep's shot and goal analysis which showed where events started and ended linking them to movement (Reep & Benjamin, 1968). Through such manual movement pattern and event data collection, useful findings regarding playing styles, tactical insights and differences between winning and losing performances were generated (Reep & Benjamin, 1968; Sanderson & May, 1977), concepts that have been analysed frequently within PA since these early attempts (Dellal et al., 2011; Fernandez-Navarro, Fradua, Zubillaga, Ford, & McRobert, 2016; Fernandez-Navarro, Fradua, Zubillaga, & McRobert, 2018).

Within patterns of play and movement analysis in squash (Sanderson & May, 1977) or soccer (Reep & Benjamin, 1968), which has been done by hand, the physical analysis was linked to technical event completion, as opposed to understanding the physical demands or movement characteristics needed to complete such technical actions. Without the use of video or computerised systems, there was little in the form of physical quantification to generate full movement patterns and physical demands of sports or positions (Reilly, 2003). The drawbacks to live, hand notational analysis to measure physical demands are that it is difficult for an analyst to focus on more than one athlete, leading to the need for numerous analysts. Additionally, reliability within and between analysts could not be tested due to the analysis occurring live with no post event video to re-assess findings. The process was also time consuming, thus limiting the amount of data gathered, and prone to inaccuracies due to the subjective analysis of movement or positioning that is influenced by observational errors or biases (Carling, Bloomfield, Nelsen, & Reilly, 2008; Hughes, 2003; James, 2006b).

Whilst physical analysis without computerised technology is difficult, manual time motion analysis (TMA) methods were still employed, with core methods, dating back to 1976, being used to observe performances and subjectively identify the movement patterns being utilised by a player (Carling et al., 2008). Examples of monitored movement patterns include standing, walking, jogging, cruising and sprinting, with each movement classification being assigned a proposed velocity to measure predicted speeds of each movement (Barbero, Vera, & Hermoso, 2003; Bloomfield, Polman, & O'Donoghue, 2004; Castagna, Abt, & D'Ottavio, 2004; Doğramacı & Watsford, 2006; Dogramaci, Watsford, & Murphy, 2011; Huey, Morrow, & O'donoghue, 2001; Krustrup, Mohr, & Bangsbo, 2002;

Mayhew & Wenger, 1985; Mohr, Krustrup, & Bangsbo, 2003). The movement classification portrayed by the athlete was commonly noted or recorded via voice recordings in a dictaphone, with the frequency and time spent in each movement classification tracked and combined with velocity values to provide estimated distance covered for each player overall or in each classification, therefore, identifying physical demands and performances (Doğramacı & Watsford, 2006; Reilly, 2003). Additions to the methods included technical actions and positional or tactical information, similar to that collected by Reep, to add context and generate comparison (Varley, Gabbett, & Aughey, 2014). Various versions of similar TMA were performed in sport with slight alterations, for example, the captain or power system (O'Donoghue, 1998; O'Donoghue et al., 2005).

Within soccer, key findings from manual TMA revealed that positional differences do occur regarding physical output and each player is on the ball less than 2% of the game. Additionally, overall physical demands were quantified in different contexts (Hughes & James, 2008). The findings from these studies allowed for early attempts at training differentiation for different positions or physical load, simulation protocols to mirror match demands and a reinforced importance of successful tactical and technical execution in soccer due to the limited time each player has on the ball. While beneficial for the aforementioned reasons, the findings were difficult to implement in a practical sense given that only one player could be analysed at one time, meaning 11 observers are needed to measure a team and 22 to measure full match demands and comparisons between soccer teams (Carling et al., 2008; Hughes, 2003; James, 2006a). Additionally, whilst the methods have been checked for reliability, objectivity and validity to deem the method appropriate in some cases, with manual recording and observer identified movement classifications, researchers have argued that some methods utilise ambiguous movement definitions (Doğramacı & Watsford, 2006). Within manual TMA, there is a strong potential for errors and inconsistencies if performed incorrectly, in addition to the inter-observer reliability benchmarks being more difficult to meet, given many observers and comparisons are necessary, increasing the likelihood of measurement differences. For example, within live, manual TMA there is a need for two analysts to record each player in a match for inter-observer reliability to be tested, increasing the number of observers to 22 or 44 for a team or full soccer match, respectively. Technological advancements related to video capture of soccer matches signified a catalyst for manual TMA regarding the ability to analyse movement patterns and physical activity post-match, whilst still utilising the same manual TMA methods discussed (Barris & Button, 2008; Blomqvist, Luhtanen, & Laakso, 1998).

3. PRESENT

Within soccer, developing on from the analytical revolution that Charles Reep and others instigated (Pollard, 2002), match footage started to become more accessible to teams. Video Home System (VHS) tapes, television broadcasts and similar technological methods became available to simply watch a game back or record and clip certain elements. From this development, practitioners could create video-based information on KPIs to compliment the data on the same indicators that could be gathered via hand notation (James, 2006a). At this point, hand notational analysis could be performed live at a match, post-match through video observation or via a combination of the two (James, 2006a).

Match capture began with broadcasters recording matches for public viewing, with technology advancing to enable filming equipment to be accessible to teams at the elite level. Initially, such footage capture was synced with analytical companies installing fixed cameras within stadiums, with such companies also coding information on specific KPIs to generate effective video clips and data points on technical, tactical and physical performance (Barris & Button, 2008; Valter, Adam, Barry, & Marco, 2006). Issues with these systems related to the high install and upkeep costs, an inability to measure training performances, combined with a lack of general acceptance of analysis at this point (Barris & Button, 2008). This type of analytical procedure has not become the rule of thumb for PA within soccer, given teams up and down the football pyramid have varied resources to invest in such analysis, although this starting point has been a large factor in the development of wider analysis options (Barris & Button,

2008). Technological advancements have led to video cameras becoming more common commodities within sports. Subsequently, computer and video technology could be utilised for analysis, with advancements upon hand notation leading to computerised notation via specialised computer hardware and software, feeding in video footage and nullifying the ability to only analyse live performances manually by hand (Liebermann et al., 2002). Combining the ability to capture footage themselves, or access footage from broadcasters, clubs could begin to generate their own analysis via training existing staff or hiring specialised analysis staff. Analysts, coaches and players could start to watch matches back from an observational and subjective point of view, or objectively analyse using software during matches for concurrent or terminal feedback, encouraging effective and objective reflection (Hughes et al., 2019) and revolutionising coaching processes (Hughes et al., 2019; Mackenzie & Cushion, 2013b). Match or training footage could be shared with players and coaches regardless of location with the integration of video platforms in soccer. Coaches could also analyse their behaviour within training sessions and identify areas for improvement (Cushion, Harvey, Muir, & Nelson, 2012). Following on from advancements within coaching and player development, wider uses for analysis have become prevalent, with recruitment processes able to benefit from video and data to identify, review or investigate potential transfer targets and make comparisons to existing players (Hughes et al., 2012; Weimar & Wicker, 2017). Additionally, wider sport science sub disciplines were able to benefit from computerised analysis, for example, medical staff received increased access to videos of injury mechanisms, strength and conditioning coaches could analyse players physicality within duels and set pieces from varied angles and have specific clips coded up to speed up review processes (Hendricks et al., 2016; Moral-Muñoz, Esteban-Moreno, Arroyo-Morales, Cobo, & Herrera-Viedma, 2015).

While the positives of PA within clubs due to technological developments are clear (Liebermann et al., 2002), drawbacks are still present. The cost of setting up an analysis department was, and still can be, significant (Hughes, 2004). Additionally, even though analysis use has featured heavily within soccer, many clubs or individuals have taken time to be convinced, with a lack of knowledge around the processes and benefits of analysis, leading to stunted uptake or a lack of training or specialist staff employment within many clubs (Pollard, 2002; Stodter & Cushion, 2017). Coaches, which PA was originally formulated to support, frequently stuck to what worked for them in the past, despite analysis challenging this through new contextual experiences and a double loop learning theory (Stodter & Cushion, 2014). The lack of PA acceptance continued as budget and staffing constraints increased lower down the soccer pyramid (Wilson, Plumley, Mondal, & Parnell, 2022; Wright et al., 2012). Progressively, though, as PA became more popular, teams further down the soccer pyramid became interested in obtaining analysis-based benefits (Thornton, Nelson, Delaney, Serpiello, & Duthie, 2019). At present, it appears that PA is now widely accepted and used to support the coaching process and wider departments such as sport science, medical and recruitment departments (Wright et al., 2012). Given that elite-level technology has constantly been improved, PA solutions that were once too expensive for semi-pro and amateur teams are now accessible, with multiple PA companies also producing more budget-friendly options regarding hardware and software (Clark & Kerski, 2014; Martin, Swanton, Bradley, & McGrath, 2018) However, to the present day, many analysis tools are still out of budget for many teams (Martin et al., 2018; Turchini et al., 2019).

The development and accessibility of video and computerised technology allowed computerised notational analysis to revolutionise performance analysis. Whilst still a manual technique via the aid of technology, with time-consuming and expensive techniques, computerised notational analysis is the most common method of KPI analysis to identify video and data insights into sporting performance (Lord et al., 2020). Linking back to previous discussions, as PA methods and technology have progressed, the original notational analysis by Reep (Reep & Benjamin, 1968) is still repeated and has been over previous decades (Bate, 2013; Garganta, Maia, & Basto, 2014; Garratt, Murphy, & Bower, 2017; Hughes & Franks, 2005; Moura, Santiago, Misuta, De Barros, & Cunha, 2007; Muhamad, Norasrudin, & Rahmat, 2013). To recap, Reep originally determined that 80% of goals were scored from three passes or less, with 50% of goals coming from possession being won in the final quarter of the pitch.

Technology has offered the ability for such goal sequence analysis to be performed more easily via video and supporting notational software, as opposed to Reep's live observation and pencil and paper method. Results have reinforced (Bate, 2013; Garganta et al., 2014; Muhamad et al., 2013) and contrasted Reep's findings (Garratt et al., 2017; Hughes & Franks, 2005; Moura et al., 2007), highlighting a varied method of success regarding possession techniques, which may be dependent upon the sampled leagues or competitions. Ultimately, the repeat of Reep's research highlights that the effective techniques utilised in early notational analysis attempts are still useful in the present, albeit with technology to support the process. The major development within analysis appears to be that recommendations from findings are not universally applied to all teams, given the variances in players, teams, competitions and other contextual factors (Sarmento et al., 2018). Moving onto additions to notational analysis, present PA through computerised notational analysis and video recordings enabled ideas for more automatic tracking systems, big data insights, automated cameras and artificial intelligence (AI) usage, building on user operated technology systems (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez, & Pino-Ortega, 2019; Filetti et al., 2017; Turchini et al., 2019). Such developments will be discussed, however, it is important to note that a key issue regarding technical and tactical performance analysis via computerised notation lies in the fact that technical and tactical performance is commonly analysed in isolation to physical performance. In the past, video-based TMA was the most prevalent physical analysis solution for many. However, the process of video-based TMA was time-consuming, analysts could only focus on one player at a time, it hampered reliability and lacked criterion validity (Carling et al., 2008; Hughes, 2003; James, 2006a). Additionally, with computerised or hand-based notation used for technical and tactical analysis, there has been a limited ability for all key components within soccer to be measured at the same time using the same techniques, increasing time consumption via separated analysis (Carling et al., 2008; Hughes & James, 2008; Pollard, 2002). This trend has continued, even with the advent of automated physical measurement systems such as global positioning systems (GPS).

To develop upon video-based TMA, microtechnology devices with micro-electrical mechanical systems (MEMS) and GPS were developed to allow for automated physical, external load tracking (Ahmadi et al., 2014; Strauss, Sparks, & Pienaar, 2019). The automation of MEMS helped practitioners circumvent the shortcomings of video-based TMA. When utilising video-based TMA, practitioners needed to analyse individual athletes in time consuming procedures. Alternatively, with MEMS, multiple athletes could be monitored automatically, allowing practitioners to focus more on data interpretation as opposed to data collection. Additionally, MEMS, such as GPS, offered additional analytical insights when compared to video-based TMA in the form of internal load measurements. When coupled with heart rate monitors, MEMS can measure athlete heart rate alongside physical output (Aughey, 2011; Castellano, Casamichana, & Dellal, 2013). GPS units were designed and introduced in invasion sports in 2006 (Aughey, 2011) to measure distances, speeds, collisions and other physical metrics of an athlete via a small unit placed between the scapula and held in the back of a vest placed over the torso (Cummins, Orr, O'Connor, & West, 2013; Pettersen, Johansen, Baptista, Halvorsen, & Johansen, 2018). Interestingly, the Fédération Internationale de Football Association (FIFA) only approved the use of GPS in professional soccer competitions in 2015 (Pettersen et al., 2018). Such GPS devices can be worn by multiple players, with each having their own GPS unit that connects to satellite signals and utilises the doppler effect to track movement over time in the same manner as manual TMA, but with more precision, automation and speed (Larsson, 2003). The benefits of GPS units, compared to video based TMA, surround the quicker and automated data collection process, with multiplayer analysis able to be completed at the same time (Dobson & Keogh, 2007). Algorithms collect data and allow instant presentation and data visualisation, though early GPS systems required the user to investigate and manipulate the data first (Duncan, Badland, & Schofield, 2009). The introduction of GPS units revolutionised the data collection processes for physical indicators, with coaches, sport scientists, strength and conditioning coaches and analysts now able to track the internal and external load of players in matches and training sessions to identify load, fatigue, reduce injury risks and periodise training effectively (Cummins et al., 2013; Rago et al., 2020).

Detailed physical information can be obtained to track development and create performance profiles (Rago et al., 2020). Progressions have led to GPS units being able to transmit live data feeds and be used as an indoor solution, without relying on outdoor GPS satellites (Luteberget, Spencer, & Gilgien, 2018; Muthukrishnan, 2009). As GPS units have progressed, GPS access has moved down from elite level sport to sub-elite and even individual athlete markets, allowing both male and female athletes at different levels of sport and ages to quantify their physical performance, assess training success and track progression (Malone, Lovell, Varley, & Coutts, 2017). Ultimately, GPS units allowed for more data to be collected, in a fast and efficient manner, allowing staff more time for interpretation of results and practical application (Rago et al., 2020).

However, to analyse GPS technology critically, we also need to assess the issues with the system. Firstly, for many years, GPS units could only be used outside, meaning indoor sports such as ice hockey, indoor tennis, squash, indoor soccer venues and other activities could not utilise the technology. However, as mentioned, recent developments have created receiver units that can be used to create an indoor GPS signal (Luteberget et al., 2018; Muthukrishnan, 2009). Secondly, cost is another consideration, compared to a video camera and computerised notational software, GPS units can be costly, given 11 units are needed to cover the starting-11 of a senior soccer team, 16 units if five substitutes are used in a match and 25 units for full squad coverage within training (Willmott, James, Bliss, Leftwich, & Maxwell, 2019), although, the units are often more time effective, more flexible and cheaper than fixed camera solutions which can automate or outsource TMA (Castellano, Alvarez-Pastor, & Bradley, 2014). Regarding reliability and validity measures, various studies have identified poor levels of inter-unit reliability, with two units from the same manufacturer coefficient of variation (CV) ranging from 20-78% (Coutts & Duffield, 2010; Thornton et al., 2019). Additionally, research has claimed GPS units struggle to identify accurate movements in small areas, or high and variable velocity movements, with values varying when quick accelerations occur (>3m/s2) (Akenhead, French, Thompson, & Hayes, 2014). When specific comparisons are made within soccer, we can see differences between physical measurement techniques. In a study by Randers et al. (2010), two different GPS units (1hz and 5hz), semi-automatic camera tracking TMA and video-based TMA methods were compared for measures of player distance, high-intensity and sprinting measures. See Table 1.

Table 1. Randers et al. (2010) presents a comparison of physical analysis results derived from varied methods.

Method	GPS 1	GPS 2	Semi-automated camera TMA	Video-based TMA
Total distance (km)	10.72 ± 0.7	9.52 ± 0.89	10.83± 0.77	9.51 ± 0.74
High intensity (km)	2.03 ± 0.6	1.66± 0.44	2.65± 0.53	1.61 ± 0.37
Sprinting (km)	0.37 ± 0.19	0.23± 0.16	0.38± 0.18	0.42 ± 0.17

The results showed that the different systems did identify varied performance values for different movement classifications. This also occurred when different time periods of the game were investigated, with lower values found towards the end of the match, typically due to game-induced fatigue (Mohr, Krustrup, & Bangsbo, 2005; Randers et al., 2010). However, as can be seen in the table, large differences occur on an inter-system level, meaning comparisons between systems should be done with caution. It is worth noting that since this comparative study (Randers et al. (2010), GPS technology has improved, with devices offering 50hz sampling rates at present (Varde'i, Cejudo, Pilar, Raiola, & Izzo, 2020). The final topic of discussion around GPS technology relates to the measurements the system calculates. GPS units are dominant in physical measurement techniques, for example, distance covered, top speed and accelerations. Tactical information can be gleaned from GPS outputs, for example, if units are assigned to certain positions within soccer, physical data can be analysed by comparing various positions and formations (Garrido, Burriel, Resta, Del Campo, & Buldú, 2022; Morgans et al., 2022). Heat maps based on positional movements can also be linked to tactical movement that coaches may encourage or discourage (Garrido et al., 2022). However, despite physical and physical-tactical analysis within GPS unit usage in soccer, technical soccer metrics such as passing frequency and velocity, passing networks, the number of touches, left leg and right

leg use are not recorded by GPS units. The lack of sport specificity makes GPS units very appealing to multiple sports, but, the lack of specific technical information relevant to individual sports is often deemed a drawback of GPS units (Chambers, Gabbett, Cole, & Beard, 2015). Though, it could be argued that sports with collision-based physical-technical actions, such as rugby or Australian rules football, that feature body to body tackling are more suited to GPS use (Chambers et al., 2015), rather than soccer which features mainly foot-based movements for all technical actions, including tackling.

At this point, this review has investigated the history and developments of technical and tactical analysis through historical hand or contemporary computerised notational systems. Physical analysis has progressed through manual TMA, video-based TMA and GPS technology, GPS being used most prominently today. Technical, tactical and physical information can enhance knowledge and decision-making with the aim of improving sporting performance.

However, with current measurement techniques, technical, tactical and physical measures are collected and analysed separately, making the process more time-consuming, more difficult to manage, with each system having their own processes, databases and presentation tools. An existing solution to this problem is the use of built-in stadium cameras previously discussed.

With the development of technology within stadium cameras, companies have been able to design software capable of tracking players' physical and technical performance, much of which through the use of artificial intelligence and automated tracking, which can be used to inform tactical insights (Hands & Xanne, 2020). However, this is not a perfect solution to athlete measurement. Despite the benefits, there are large financial requirements, stadium infrastructure and an elite-level organisation which normally encompasses the previous two points (Barris & Button, 2008). Additionally, fixed stadium solutions only allow for match play to be monitored. In soccer, teams can train up to seven days a week, meaning training demands are not accounted for through the use of stadium cameras, limiting performance profiles and the use of data for performance tracking and injury risk (Barris & Button, 2008; Carling et al., 2008; Hands & Xanne, 2020). Camera-based alternatives to fixed stadium cameras include portable automated tracking cameras such as Veo or Hudl Flex, however, similarly to stadium cameras, portable camera systems can record and analyse technical and tactical events, but physical analysis is not possible, nor is event tracking in training situations (Turchini et al., 2019).

4. PRESENT TO FUTURE

Within contemporary PA practices, there has been a gap in the market to combine technical and tactical information with physical measures, providing a more well-rounded view of objective performance. Utilising technological advancements, within soccer, Playermaker foot-mounted inertial units have been designed as a wearable piece of technology featuring two MEM units worn in a pair of elastic bootstraps that sit over the top of the left and right boot on the foot. The system utilises a gait analysis algorithm with a six-axis gyroscope and accelerometer for physical data collection, with measures including total distance, sprint distance, work rate, number of sprints and accelerations and decelerations (Waldron, Harding, Barrett, & Gray, 2021). However, the main advancement within Playermaker technology has the ability for the units to measure technical actions through sensors within the units, allowing for the number of touches, number of releases, release velocity, left and right leg use, number of possessions and time in possession to be measured. From a tactical point of view, many of the technical actions contribute to tactical analysis, for example, the amount of time creative players are on the ball for, how much players are involved in passing sequences, how left and right leg usage allows for varied tactical progressions and passing angles, release velocity for goalkeepers to hit certain zones of the pitch and more. When one team wears Playermaker units, no interaction occurs regarding network analysis and passing matrixes, however, when both teams wear Playermaker units, additional tactical insights can be gained through possession measures, number of passes, pass success and passing matrixes between players. Playermaker foot-mounted inertial

units are the first wearable technology allowing soccer analysts, coaches and players to measure comprehensive physical, technical and tactical actions within one solution. Due to this, Playermaker nullifies the previous issues regarding separate technical, tactical and physical analysis, allowing practitioners to combine analysis, speed up workflows and perform less computerised notational analysis due to the ability to sync video with all data points produced by Playermaker foot-mounted inertial units.

Despite the benefits of the Playermaker system, at the time of writing, the system is still relatively under-researched, with only 17 studies featuring the system within varied topic areas (Dasa et al., 2022; Davidson, Barrett, Toner, & Towlson, 2024; Emmonds et al., 2023; King et al., 2024; Lewis et al., 2022; Losada-Benitez, Nuñez-Sánchez, & Barbero-Álvarez, 2023; Marris, Barrett, Abt, & Towlson, 2022; Myhill, Weaving, Barrett, King, & Emmonds, 2022; Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Quinn & Atkins, 2023; Salter et al., 2023; Sandmæl & Dalen, 2023; Sandmæl, Van Den Tillaar, & Dalen, 2023; Shushan et al., 2023; Towlson et al., 2021; Waldron et al., 2021). One key drawback is that, although FIFA approved (FIFA, 2023), the system is currently only applicable to soccer, given the metrics and measurement systems, leading to a major drawback compared to multisport GPS use (Malone et al., 2017). Additionally, there are question marks over coach and player perception of the Playermaker units. Previous research within performance analysis has investigated the opinions of coaches and players as the key recipients of performance analysis-based insights (Andersen, Francis, & Bateman, 2022; Reeves & Roberts, 2013).

Across all sports, whilst some opposition and disengagement occurs depending on the type of analysis delivered, for example, analysis can be used as a stick to beat players with causing demotivation (Mackenzie & Cushion, 2013a; Reeves & Roberts, 2013), analysis is generally accepted and valued by both coaches (Mackenzie & Cushion, 2013b) and players (Wright et al., 2016). The case is the same when we isolate computerised notational analysis (Wright, Carling, & Collins, 2014) and GPS based perception research (Nosek, Brownlee, Drust, & Andrew, 2021; Weston, 2018). Many player perception studies investigating the value of PA focus on soccer, reinforcing the acceptance and encouragement of analysis within the sport that Playermaker is based. This suggests that while specific player perception research regarding Playermaker has not been published, it could be argued that PA and wearable technology data is generally accepted by players. Nonetheless, research to confirm this is recommended (Davidson et al., 2024).

Player engagement regarding comfort and interaction with technical actions is also a consideration for Playermaker, with GPS research highlighting that some athletes find the vests and units comfortable and unobtrusive to movement, whereas others athletes dislike wearing GPS devices and cite discomfort as a reason for such opposition to the technology (Luczak, Burch, Lewis, Chander, & Ball, 2020). There is a clear need to determine if players come to the same conclusion with foot-mounted inertial units being placed over players boots that are directly involved in the technical execution of control, dribbling, passing, shooting and any action in which the boot comes into contact with the ball.

Regarding coaches' perceptions of analysis, it is important to understand what metrics or KPIs coaches feel useful to support their practice, with a key aim of PA to support the coaching process. Research within physical, technical and tactical soccer analysis has found that coaches believe high intensity actions (Nosek et al., 2021), shooting related actions (Herold, Kempe, Bauer, & Meyer, 2021) and formation information (Bauer, Anzer, & Shaw, 2023) to be key to success and, therefore, worthwhile measures for the analysts to record and feedback. For Playermaker, the units record metrics similar to those identified as useful by coaches for physical and technical measures.

However, there is a lack of research detailing whether coaches specifically find the number of touches, releases, foot usage, number and time spent in possessions and the related tactical insights useful at all levels of the game, and if so, the hierarchical importance of each measure. Additionally, for players, there is also a lack of research to

determine if players also find the KPIs that are generated by the Playermaker system useful for self-reflection and goal setting (Wright et al., 2016).

As mentioned, wearable technology, in the form of GPS units, has faced criticism regarding reliability and validity, though it has generally been accepted as the go to system for physical measurement (Malone et al., 2017). Playermaker units have been subject to some reliability and validity testing, with positive results (Marris et al., 2022). However, based on the research, it is apparent that intra or inter-observer reliability was performed in training environments (Marris et al., 2022) via level of agreement testing (Cooper, Hughes, O'Donoghue, & Nevill, 2007). Despite percentage level of agreement measures being used, with benefits to that reliability measurement system, a question begs whether the percentage level of agreement is a sophisticated enough measure to ensure effective reliability measures when analysing the stability of KPI values in soccer performance (Tenga, Kanstad, Ronglan, & Bahr, 2009).

The popular (Cooper et al., 2007) model is beneficial, but at nearly 20 years old, with additional reliability testing methods available, featuring more detailed statistical analysis alongside upper and lower thresholds and confidence values, there is a need for a deeper examination of analytical tools (O'Donoghue, 2014). Therefore, it would be an effective experiment to examine the inter and intra-reliability of the Playermaker, GPS and notational analysis systems in training and match play scenarios to determine deeper insights into the consistency of measurement within and between systems. Additionally, no principal component analysis has been done on Playermaker KPIs. For this reason, research featuring inter and intra-observer reliability testing, in training and match play, with varied reliability measures and principal component analysis could be performed to determine the reliability and validity of Playermaker foot-mounted inertial units. Regarding the samples, currently, elite male and female samples of varying age have been used across 6-month maximal periods, leaving longitudinal samples, or samples featuring amateur and semi-pro athletes, unresearched. Additional research gaps are also present regarding positional comparisons.

Within PA, another discussion point surrounding the notational analysis and wearable technology such as GPS and Playermaker technology measuring technical, tactical and physical metrics is the match-to-match variability aspect. Research has attempted to quantify the number of performances needed to generate a stable performance profile in technical, tactical and physical KPIs for effective judgement and decision-making (Baptista, Winther, Pedersen, Johansen, & Pettersen, 2023; Gregson, Drust, Atkinson, & Salvo, 2010; Liu, Gómez, Gonçalves, & Sampaio, 2016). However, variability research on technical, tactical and physical measures within Playermaker systems is lacking, meaning applied practitioners and researchers are none the wiser as to how many performances are needed to create a performance profile that can be used for decision-making to effectively utilise Playermaker technology.

There is a lack of understanding on values per position, ability level, and the amount that values vary from match to match, making it unclear how many performances are needed to identify talent, appraise development or regression, or simply create benchmarks. Findings from variability studies could inform how trustworthy analysis on Playermaker KPIs can be and how worthwhile comparisons between standards and positions are.

Overall, whilst technology has developed within technical, tactical, and physical analysis from hand notation to computerised notational analysis and wearable technology, no system encompassing technical, tactical and physical measures has been covered by coach and player perception research, reliability and validity testing and a full analysis of match and training demands across multiple seasons to uncover the holistic demands of soccer. A study, or series of studies, of this kind could help to determine what coaches and players find most important within PA and determine if modern measurement methods are fit for purpose to support training and match analysis from identification, development and performance perspectives.

5. DECISION-MAKING MATRIX

This narrative review has discussed performance analysis techniques for technical, tactical and physical analysis. Based on these discussions, it appears that analysts, coaches, players and others could benefit from a decision-making matrix to appraise their current resources and infrastructure before deciding which techniques are attainable, applicable and beneficial to them. Below, Table 2 presents a technical, tactical and physical analysis decision-making matrix, taking inspiration from the decision-making framework for implementing technology in sport by Windt et al. (2020).

Table 2. A decision-making matrix is presented to outline the methods available for analysis data collection at varied resource contexts.

Resources & infrastructure	Technical analysis	Tactical analysis	Physical analysis	Technical, tactical & physical analysis
No budget or resources	Live: Hand-based notation	Live: Hand-based notation	Live: Hand-based notation & TMA	Live: Hand-based notation & TMA
Video recording capabilities	Live or post: Hand-based notation	Live or post: Hand - based notation	Live or Post: Hand-based Notation & TMA	Live or post: Hand-based notation & TMA
Computer notational analysis software	Live or post: Computer -based notation	Live or post: Computer-based notation	Live or post: Computer-based TMA	Live or post: Computer-based notation & TMA
Stadium infrastructure	Stadium installed technical monitoring systems	Stadium installed tactical monitoring systems	Stadium installed physical monitoring systems	Stadium installed technical, tactical and physical monitoring systems
Wearable technology	Playermaker foot-mounted inertial units	Playermaker foot-mounted inertial units or GPS units	Playermaker foot-mounted inertial units or GPS units	Playermaker foot-mounted inertial units

6. FUTURE

Regarding the future of performance analysis, recent indications suggest that virtual reality and artificial intelligence have started to, and will continue to develop within performance analysis, sport and soccer (García-Aliaga et al., 2023; Li & Zhang, 2021; Thatcher, Ivanov, Szerovay, & Mills, 2020). Therefore, while a large research base has not been developed yet, it is a worthwhile discussion to identify current and future developments with the next level of technology entering sport. Thus far, AI is utilised within automated and semi-automated tracking cameras (Hands & Xanne, 2020) wearable technology (Adesida, Papi, & McGregor, 2019; Aroganam, Manivannan, & Harrison, 2019; Toner, 2023) big data, machine learning concepts and more (Araújo, Couceiro, Seifert, Sarmento, & Davids, 2021; Sampedro, 2021).

Within PA, it appears that while AI tools can be utilised to reduce time demands, enhance efficiency, and in some cases improve accuracy of data collection in comparison to human PA operators, caution must be utilised to avoid blindly following automated processes without quality assurance procedures. In addition, despite benefits of AI integration into workflows, the delivery and feedback of information is still driven via coach or analyst communication, with AI tools seemingly incapable of applying specific contexts and thought processes that coaches and analysts can use to accompany data and video. Therefore, whilst AI can positively impact processes and allow for more focussed analysis interpretation as opposed to data collection, the delivery of analytical insights currently remains largely unchanged. Regarding actual training practices, virtual reality systems simulating the training and match environments have been created to allow players to experience realistic scenarios to test their technical and tactical performance alongside psychological factors such as decision making (Bird, 2020; Neumann et al., 2018). This shows that while the delivery of PA insights may remain practitioner led, advanced technology can support the coaching process by enabling an artificial practice environment for players to train performance components highlighted via PA insights.

With technology and AI supporting PA processes, increased amounts of analysis can be performed. While PA insights are still delivered by coaches and analysts, it is worth exploring the impact that PA processes, as well as PA delivery, can have on athletes. Psychological and social analysis is common in many quantitative research papers overall, but regarding soccer and PA, inclusion of these components has been most prevalent in qualitative research on coach and player perceptions of PA (Andersen et al., 2022; Wright et al., 2016). Given the increase in athlete monitoring in the form of video, data and wearable technology, the psychological and social impacts of PA from a performance and personal perspective are arguably more important than ever (Neupert, Gupta, Holder, & Jobson, 2022). Research has determined that PA can influence arousal levels and invoke positive or negative feelings based on modelling feedback, criticism and highlighting performance-related information to an individual or group (Magill, Nelson, Jones, & Potrac, 2018; Middlemas & Harwood, 2018; Wright et al., 2016). Individuals and groups are found to have preferential learning environments related to when, what and how PA information is feedback. Information delivered in the optimal manner for individuals and groups can enhance the feedback process, increase motivation, learning and potentially positively impact performances. Information delivered in a sub-optimal manner can damage the feedback cycle between analysts, coaches and players (Magill et al., 2018; Middlemas & Harwood, 2018; Wright et al., 2016). With increasing athlete monitoring and new technology being produced for monitoring and analysis, constant consideration of monitoring and feedback techniques are required, with responsible PA for effective, ethical analysis delivery between analysts, coaches and players being a key consideration (Jones, Parker, & Daniels, 2020; Jones & Toner, 2016).

Reinforcement of responsible PA comes from the potential issues associated with constant performance and lifestyle monitoring that now exists in sport. Training, matches, diet, sleep, alcohol, drugs, lifestyle and activity-based information are all monitored for supposed performance insights and improvements via PA and sport science tools (Jones et al., 2020; Jones & Toner, 2016), many of which involve the use of AI technology (Sampedro, 2021), but, we need to question their appropriateness. The fact that both adult and child participants in sport and soccer utilise analysis for benefits linked to performance appraisal, talent identification, recruitment, opposition analysis and more, it must be discussed if children should be monitored in the same way as adult or elite level athletes, considering the benefits as well as potential issues that analysis can have on athletes of different age and ability. The professional world of sport and soccer can feature a pressurised working environment, with criticality on performance and analytical scrutiny commonplace, often leading to negative consequences in the aim for performance improvement within players (Manley & Williams, 2022). Whilst performance-related demands at the elite level can be expected, it is important for analysts at the semi-professional or amateur level, as well as the elite level, to consider whether the practices are suitable for athletes with a susceptibility for negative reactions to critical feedback, a decreased level of performance expectation and varied reasons for participation. Within this, it should be considered if more responsible and inclusive methods should be adopted to encourage performance improvements as opposed to demanding them, whilst stimulating motivation and enjoyment levels within athletes (Barker-Ruchti et al., 2021).

7. CONCLUSION

Overall, from this narrative review, it can be stated that PA in sport and soccer has developed significantly and continues to do so (Mackenzie & Cushion, 2013a). Evolutions within technology have lead observation into the use of video footage, hand notation to develop into computerised notation, computerised notation into wearable technology systems and an industry where technical, tactical and physical measurements are possible at all levels of sport and soccer (Sarmento et al., 2014).

Whilst progression is beneficial, there are still question marks regarding the level of academic research comparing multiple methods of analysis on an individual, team and combination basis. Newer technologies, such as Playermaker, are still under-researched to be utilised at face value, although the technology does appear to produce

analysis that GPS units and computerised notation cannot, or are deemed sub-optimal to be used for. In different levels of soccer, with varied resources and infrastructure, at the elite or sub-elite level, male and female samples can all measure technical, tactical and physical measures within their players. The decision-making matrix can be utilised as a guide to execute the aims of the club and provide a simple appraisal of what can be used to achieve what goal, with multiple means of achieving the same goal possible, despite technological developments.

The final point is a call to arms for responsible PA. Whilst analysis can be utilised at any level, age or gender, that does not mean that all players need to be measured in the same manner, with ethical considerations based on athlete monitoring and the impact of critical performance feedback (Jones et al., 2020). With technological developments also involving AI and virtual reality, analysts need to be careful that analysis does not become an irresponsible, over-monitored, dehumanised process (García-Aliaga et al., 2023; Thatcher et al., 2020). What originally started to aid coaches and players with performance info, could turn into the use of technology and monitoring for the sake of it, with negative implications as opposed to positive. We must recognise the due diligence needed to utilise effective measurement systems and levels relevant to the level, age and gender of players, with one system seemingly unable to measure all performance aspects. However, we must do so whilst resisting the temptation to utilise every method of analysis, causing over-analysis that is potentially invalid, unreliable or ineffective when delivered to players (Jones et al., 2020).

List of Abbreviations

PA – Performance analysis.

TMA – Time motion analysis.

GPS – Global positioning system.

MEMS – Micro-electrical mechanical systems.

VHS – Video Home System.

FIFA - Fédération Internationale de Football Association.

AI – Artificial intelligence.

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