An Applied Approach to Attacking Effectiveness in Professional Football

By

Emiel Schulze

This thesis is written for the award of the title Doctor of Philosophy (PhD) from the Medical Faculty, Saarland University, Saarbrücken, Germany.

Institute of Sports and Preventive Medicine

Saarland University

Supervisor: Prof. Dr. Tim Meyer

24-05-2022

Declaration of Authorship

I, Emiel Schulze, certify to the best of my knowledge and belief that this thesis does not:

1. Incorporate any material previously submitted for a degree or diploma in any institution of higher education without acknowledgement;

2. Contain any material previously published or written by another person; where due reference is made in the text; or

3. Contain any defamatory material.

I also grant permission for the library at Saarland University to produce duplicate copies of my thesis as required.

Signature: **Emiel Schulze** Place and Date: **Stuttgart, 24-05-2022**

Abstract

With ever growing financial invest in elite (association) football (soccer), it becomes increasingly more important to operate at the highest possible standard. A stable football organisation allows for more long-term success and greater investments. With this, objective and thorough analyses of the work done and future requirements become irreplaceable. This in turn opens the door for the instalment or development of analysis departments and analyst positions within elite football teams. These analysts, usually coming from a scientific background, rely on accurate and reliable data. The quality of the analyses, or analysts for that matter, then depends on the work done and choices made. The current research programme was designed to guide practitioners to effectively analyse and apply the data currently collected in elite football.

Because match analysis in football has come a long way since first mentioned in a scientific journal in 1968. From basic notational metrics collected live during matches, through comprehensively studying video footage and having computers take over the collection of match parameters altogether. Currently, no matter whether positional time-motion data, metrics describing all on-the-ball match events or computerised combinations of the two are taken into consideration, the possibilities are seemingly endless. That means, analysts should be aware of the context of the data in order to appropriately interpret the results. Generally speaking, the focus and goals of the analyses should be clear and that is where this research programme started off.

In many elite sports, like football, being successful depends on winning. Whether this is a short-term requirement or is treated as a long-term process with potential setbacks anticipated, is a decision made by clubs and directors. On the field, where the coach is responsible and analysts often support decision making, success often depends on scoring goals.

Regardless of the fact one wants to score more or concede less than the opponent, at least one goal is required to win. That is why the current research programme acknowledged a goal to be the most decisive event in elite football. With that notion in mind, multiple studies were designed to answer the question of how teams can become more effective in scoring goals.

The first study was designed to determine the differences between shots that led to a goal and shots that did not. This was done by studying attempts made from statistically identical locations on the pitch, however with changing situational circumstances (context). It was found that the magnitude of effect of opponent positioning changed for different shooting locations and offensive players. The results showed that the selected contextual factors were not able to explain all variance in shooting outcome, however that they should be kept in mind whilst analysing match events.

Generally, since opponent presence and pressure were found to influence some shots, the notion that time (e.g. space) is of importance during an attacking sequence came to light. How and when this space between opposing players came to be, was studied in the second investigation of the current programme. Since (theoretically) balance exists between both teams of eleven players, a perturbation of this balance needs to occur prior to a goal scoring opportunity. Expert observers qualitatively analysed a series of match events between elite teams from ball recovery to the moment of the shot. Specific playing styles or actions were not identified to disturb a team's balance; however, agreement was found for a timepoint approximately five seconds prior to the shot to be most detrimental. Furthermore, experts showed stronger agreements when a sequence led to a goal, although they were unaware of the outcome. This importance of a strong perturbation, highlighted, again, the significance of sufficient space for an attacker to release a threatening shot.

Finally, also since the balance was disturbed some time before the shot, there seems to be more at hand during a successful attack than a simply well-executed shot. After validating a low-cost tracking system in the third study, so this could be used in a sub-elite environment with a team willing to share full time-motion and tactical data, the final, fourth, study was designed. Here, physical parameters prior to shooting attempts were compared for different outcomes. It was found that an increased physical output, describing both the covered distance and intensity of movements, and fewer defenders behind the ball related to greater attacking success. Similarly, when defenders had to cover more distance prior to a shot, the chances of conceding a goal increased too. Together with a noteworthy relationship between lower match output and both attacking as well as defensive success, the importance of creating space or covering opponents were highlighted once more.

Conclusively, by taking football's most decisive event, a goal, into account, the understanding of how to play more effectively has considerably grown. At the same time, the current research programme showed how analysts could effectively apply commonly collected match data into day-to-day practice. By identifying and acknowledging the context during crucial events, more information towards improved decision making and player profiling may be gathered. Future scientific studies may take this applied approach as a guideline for worthwhile large-scale solutions. With machines capable of learning along the way and taking comprehensive datasets into account, the potential for match analysts is substantial. With science supporting practitioners to answer the questions asked by coached and directors, financial investments in both fields may follow and allow for a bright future.

Table of Contents

List of Tables

List of Figures

Abbreviations

CL	Confidence limits
CV	Coefficient of variation
DEF	Most important defensive reason for the occurrence of the scoring opportunity
ES	Effect size
FIFA	Fédération Internationale de Football Association
GPS	Global positioning system
GSO	Goal scoring opportunity
HDOP	Horizontal dilution of precision
HID	High-intensity distance
IMU	Inertial measurement unit
KPI	Key performance indicator
LPM	Local position measurement
OFF	Most important offensive reason for the occurrence of the scoring opportunity
PCA	Principal component analysis
SD	Standard deviation
SEC	Point in time deemed crucial for the occurrence of the scoring opportunity
SEE	Standard error of the estimate
SLP	The slope over every four consecutive ratings of defensive balance
TE	Typical error
UEFA	Union of European Football Associations
xG	Expected goals

Acknowledgements

The downside of taking a while the finish a PhD; the list of important people deserving gratitude becomes properly extensive. However, there is only one person where I can start off: Prof. Dr. med. Tim Meyer. It is only because you selected me to join the international PhD-programme in Saarbrücken, that I currently stand where I do. As main supervisor of my work, you have been extremely helpful and supportive and I cannot thank you enough for everything you have done, during my time in Saarbrücken and after I left to join VfB Stuttgart. It humbles me to be able to rely on your support and I am certain, our paths will cross again.

With Prof. Meyer being the supervisor of my work, a very special thanks is also deserved by the supervisor of my PhD-life: Dr. Sabrina Forster. You made my life and that of all other PhDs so much easier and your help, inside and outside the office, has been so valuable. Thank you for your support, patience and making me feel welcome from the first day onwards.

When talking about the first day onwards, there is one more person that deserves a very warm and exclusive thank you: Dr. (sounds good) Ross Anthony Julian. Even when a know-it-all Dutchie might not be the easiest to deal with, you were there for me from the very beginning and I am honoured to call you one of my dearest friends today. Thank you for supporting me in my work and making life in Saarbrücken so great! Even if that delayed finishing this thesis by some time, I would not have wanted to experience this journey any other way!

With Ross being listed on two of my publications, he is my most-trusted (non-supervising) co-author. However, I would also like to take this opportunity to thank all other co-authors. For the first study, the staff of Benfica Lab, led by Nuno Mauricio and his team, who invited me to join them and welcomed me in the beautiful Portuguese way of the life. And for the second study, although our first meeting was only a few days after I moved to Germany,

Christofer Clemens and Stephan Nopp. I thoroughly enjoyed our meetings and talks in the DFB hotels around the country and I am forever thankful for your insights and support.

The same can be said for Jan Schimpchen, Dr. Sascha Schwindling and Dr. Florian Beadouin. Although you are not listed on my publications, none of them, including this thesis, would have been completed without you. On top of that, Jan, I am so thankful for everything else you have done! Including your guidance whilst recovering from knee surgery. I am really looking forward seeing you more often in the future and curious about your upcoming work.

Who also have not been included as co-authors, but have played a major role in my final study are Michael Wiesinger and Oliver Beer. Thank you for adopting me in your staff and for showing me the ropes within the daily practice of professional football. I extremely enjoyed our (league-winning) season together and it shaped me to the analyst I am today.

For the thesis itself I would like to say a special thank you to George Syrianos for taking the time and effort to help me finish my doctorate journey off in style. I know you are incredibly busy with work and family, so it is with extreme gratitude that I got to run my thesis by you. Your insights and remarks have been a huge help and definitely boosted my confidence.

For everyone else involved in the process of writing my PhD: thank you! Not without extra mention my fellow PhDs, with whom I got to share all the highs, lows and even an apartment. On top of that my friends, especially in Stuttgart, who always pushed me to keep at it, even when times were rough or distractions were looming.

Finally, I would like to mention and express my gratitude to my family, for standing by my side after leaving for Germany. Thank you for supporting me and the countless visits, which made life so much better! On that note, thank you Tammy; for everything! The writing retreats were so much better, knowing you were there to fall back on and enjoy life-after-the-PhD with!

Preface to the PhD

This thesis follows thought processes and critical analyses of the current scientific body of literature along published and peer-reviewed original scientific investigations. These manuscripts appear unchanged in content, however possibly altered in style throughout this work, with the actual published versions attached as appendices. The thesis flows from applied practice to scientific approaches and back, with the manuscripts forming the scientific basis. I have aimed to fulfil my role as sport scientist to serve the sport and athletes in the first place, whilst concurrently developing a scientific programme. The investigations leading from it were conducted in male football environments, thereby, players will be consistently referred to as male athletes throughout this programme. However, the same concepts could just as well be translated to female players. Generally, many of the ideas and considerations that form the basis of the current research come from conversations with coaches and players. Obviously, meetings and discussions with colleague scientists at numerous conferences or gatherings have also been very insightful and useful. However, it might be worthwhile to keep in mind, that this research has originated from within professional sports organisations. A place where, sadly enough, science often still remains a loaded term. The scientific community may have countless studies and extensive progress ahead of them to change that. I will be that last one to claim that this project is going to change the world of science or football for that matter. However, again, I have merely aimed to put the thought processes of professionals in the field into a scientific approach to strengthen the outcome and usefulness. The following research programme and the studies that resulted from it, might be best interpreted as possibilities to develop oneself, one's work, a player, a team, a field or the application of science. One is more than allowed to question the setups, analyses or conclusions drawn from it. However, at the same time, if the current programme starts a new thought process and novel scientific or practical ideas stem from it, this thesis has done exactly what I aimed for it to accomplish.

Chapter 1

Introduction into match analysis in football

1.1 Collecting match data; from past to present and beyond

On the 15th of July 2018, around 19:50 local time in Moscow, a whistle sounds in the Luzhniki Stadium. With that signal, France becomes the world champion association football (soccer). The world governing body (Fédération Internationale de Football Association, FIFA) reported a record audience of 1.12 billion spectators worldwide for that final and 3.57 billion for the tournament (Media Release 21-12-2018; www.fifa.com). Due to such numbers, football is regarded as the most popular sport in the world. At the time of writing, FIFA even has more members than the United Nations (211 to 193; www.fifa.com, www.un.org). With this popularity, enormous financial markets have erected and possibilities to invest have grown accordingly. Every season, football clubs break transfer and salary records to have their desired players compete in their colours. Furthermore, financial investments are made in every aspect of the sport. Not merely in the players competing on the field, also in employees in the offices, running clubs and sports organisations like the international businesses they have become.

To ensure transfer money is well spent and players are able to perform up to their full potential, larger and more professional staffs are put together. From a multitude of coaches and specialists on the field, to top-of-the-line physical and medical support. To objectify the interpretation of the physical loading the players have to endure on a daily basis, all movements and actions, in both training or matches, are recorded and analysed. With regularly 20 to 25 players in a squad and increasing technological sampling rates, enormous data sets are collected. As such, supported by developments in modern technology and science, match as well as performance analysts have been getting more predominant roles within football teams (Gréhaigne et al., 2001). With computers capable of processing more data at increasingly faster rates, endless possibilities have arisen for these analysts to describe and model football matches and the behaviour of players (Rein and Memmert, 2016). Consequently, with so many data points, one can get easily lost within the numbers and vectors. To get the best understanding of what future developments in the field of match analysis could offer the sport, a comprehensive overview of the scientific background is warranted. The current body of literature, peer reviewed by colleagues and experts in the field, will be used to guide this overview of how and what data is collected.

One of the first published studies on match analysis was performed by Reep and Benjamin in 1968, who presented that a great deal of chance is part of ball games like football, since teams with more scoring opportunities did not always win (Reep and Benjamin, 1968). However, instead of accepting fate and let chance decide the outcome, they also stated that it is possible to build successful playing styles based on minimising the effect of chance. This theory has been confirmed since (Hughes and Franks, 2005) and shows it is worthwhile to analyse playing styles, which paved the way for further studies. Pollard and colleagues, for example, already presented how match parameters could statistically separate playing styles (Pollard et al., 1988). The match data from these studies was collected by hand, making this first step into match analysis a form of notational analysis. By recording on-the-ball actions, metrics describing team play in possession emerged (Pollard and Reep, 1997). Such statistics, recorded live during matches, did not require post processing or video feedback, making it the easiest-to-apply form of analysis. However, at the same time, this process would most likely lead to human errors and highly generic metrics. In order to enhance precision and provide additional and more detailed quantitative parameters describing standalone events, video replay is required. Such notational analysis, with correction loops in place, is still common practice to date.

Apart from allowing more advanced notational statistics, such as passing or shooting metrics, having access to video footage opened more pathways for different forms of match analysis. Already in 1985, Mayhew and Wenger described the activity profiles of players by reviewing match footage (Mayhew and Wenger, 1985). This practice has been repeated more often since (Bloomfield et al., 2007; Mohr et al., 2003). And whereas energy expenditure of football players had to be estimated before, as presented by Reilly and Thomas in 1979, Bangsbo and colleagues were one of the first to present data on the physical output, in form of distance covered, of football players during a match by closely analysing match footage (Bangsbo et al., 1991; Reilly and Thomas, 1979). With various studies to follow, a more detailed understanding of the physiological demands of the sport was built (Bangsbo et al., 2006).

Video footage itself can even present different opportunities. Whereas close-up images allow for in-depth analysis of player motions, wide view perspectives open up qualitative tactical analyses for coaches and practitioners. Since all players are continuously on screen, off-the-ball behaviour can be analysed as if the analyst was present at the game. With technological developments, machines have become capable of recognising players from such perspectives too. Consequently, technologies utilising a multitude of cameras were introduced, capable of automatically tracking player positioning (Di Salvo et al., 2006). This introduction of computerised analyses has opened many new doors, allowing for advanced developments.

In 2006, the first scientific study validating a tracking system like this was published (Di Salvo et al., 2006). These systems rely on six to eight high-resolution cameras, together covering the whole playing surface (see Figure 1). By this, a two-dimensional map of the pitch is built. Through colour-comparison, players are identified and mapped to determine positioning. By sampling at high-frequencies, accurate positional data is provided. However, human input is still required to control for errors in player recognition, making it a semi-automatic tracking solution (Castellano et al., 2014). When players huddle, it is possible for the system to mix players up, since the capture resolution is often not high enough to identify player numbers or features. Therefore, all match data has to be initially corrected during the match, with another level of data repair being performed post-match. As such, live data is not optimally accurate and human operators remain irreplaceable to date (Linke et al., 2020).

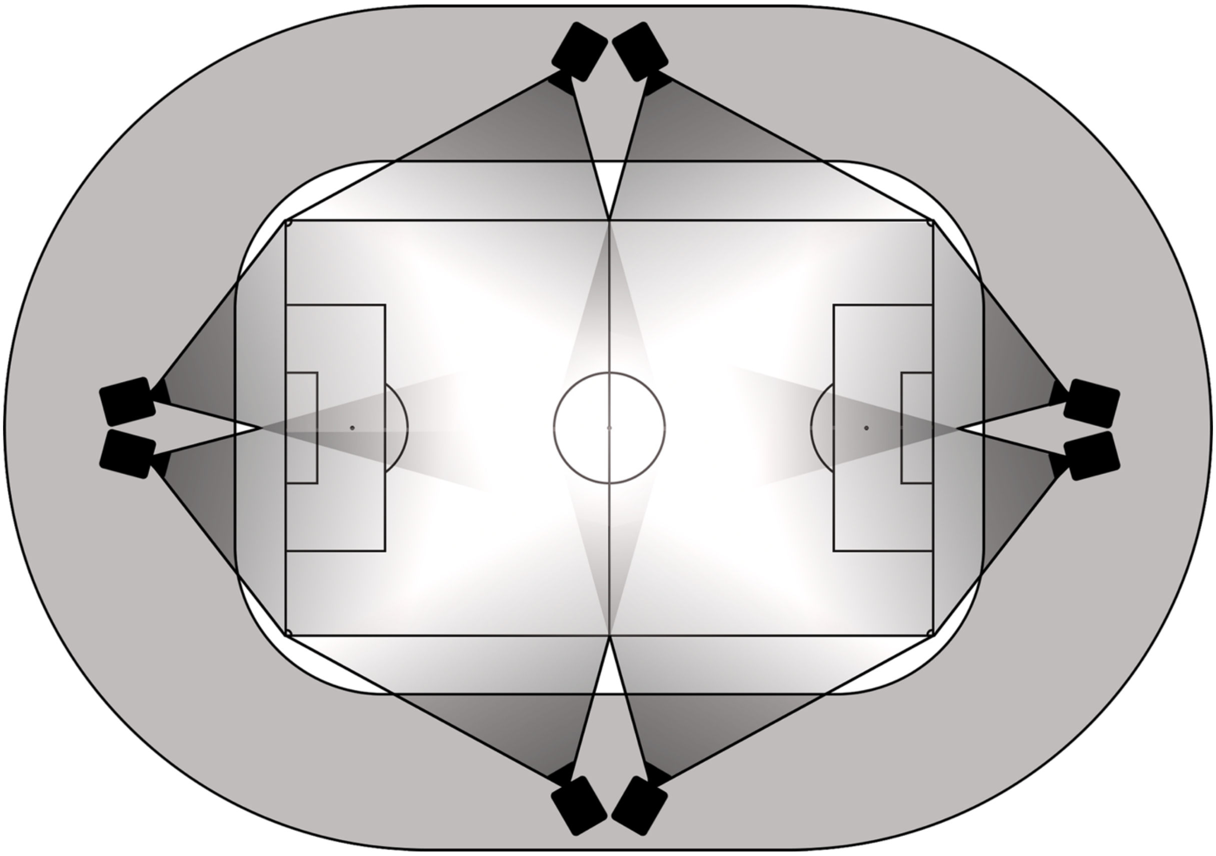

Figure 1. *Graphical representation of a multiple camera setup covering playing surface to simultaneously collect time-motion data of all players.*

Technologies which alleviates such issues, introduces trackers which have to be worn by the players (Buchheit et al., 2014). Now, positioning is not calculated by cameras, but, for example, by antennas receiving the signal from the player trackers and mapping them on a similar two-dimensional pitch, forming a Local Position Measurement (LPM) system (Frencken et al., 2010). Hereby, human input is no longer required, leading to the highest accuracy of tracking systems available (Linke et al., 2018). However, with this technology, players do have to carry a tracker with them, which introduces different issues. Only on July 8, 2015, FIFA allowed players to wear tracking devices (wearables) in official matches, meaning until that date, such systems could not be used in official matches. A second issue, similar to the semi-automated tracking systems relying on installed and calibrated cameras, relates to mobility (Stevens et al., 2014). Every pitch needs to have a setup of antennas, usually meaning collecting match data away from home becomes impossible. Or even for teams with multiple training grounds, as many systems have to be installed to guarantee complete coverage.

This is where the Global Positioning System (GPS) comes into play. These systems completely justify the terminology "wearables", as they essentially only require each player to wear a single tracker (Jennings et al., 2010). Through satellite connections, the positioning is calculated and, consequently, activity data follows from these calculations (Larsson, 2003). As this technology solely depends on a clear sight of the sky, data can theoretically be collected at any outside location (see Figure 2). The accuracy of this data has, however, been found to be strongly dependent on sampling frequencies and satellite reception (Beato et al., 2018; Johnston et al., 2014). Also, since stadiums usually feature roofs (partly) covering the sky, data accuracy is often negatively affected (Buchheit and Simpson, 2017).

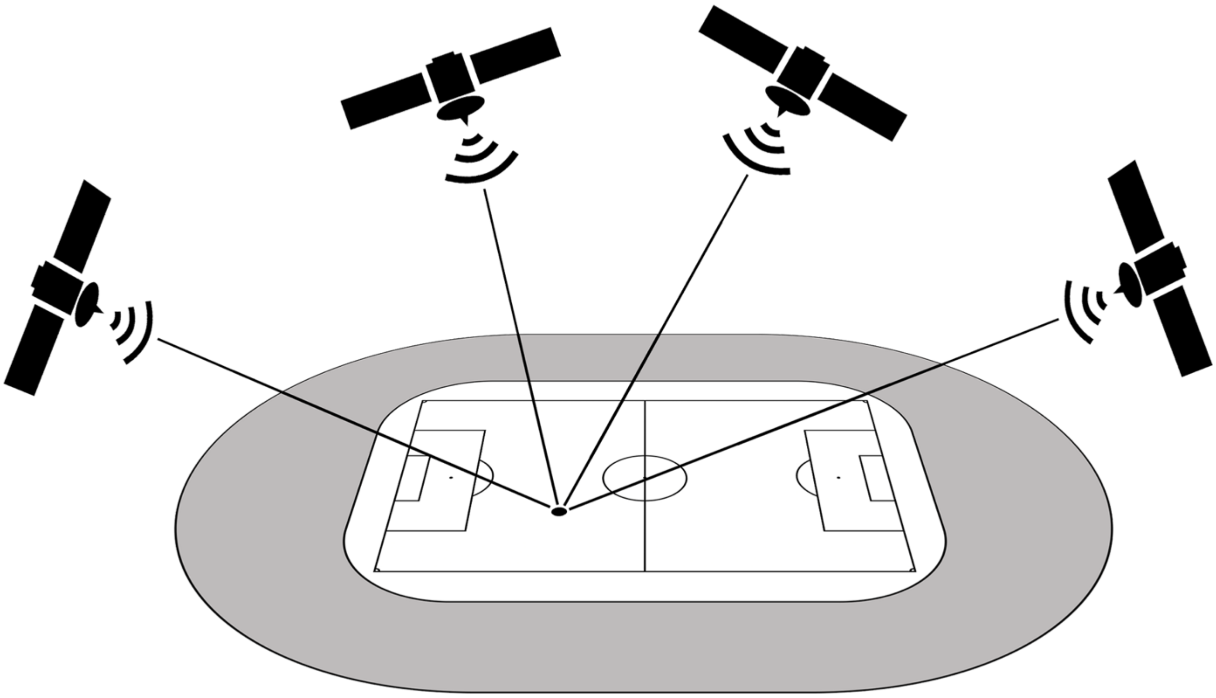

Figure 2. *Simplified graphical representation of the functionality of a GPS tracking solution, with multiple satellites providing positional information for a single player's tracking device.*

In order to minimise the effect of impaired satellite reception, the internal hardware of both LPM and GPS trackers has made continuous improvements. On board are not just antennas for the system's signal anymore, high-frequency accelerometers have been added to measure even the smallest of movements (Malone et al., 2017). The importance of such advancements becomes clear when realising that all previously introduced time-motion analysis systems basically provide two-dimensional positional data (Edgecomb and Norton, 2006). The most basic way to calculate velocity, depends on the difference in positions over short periods of time (positional differentiation). With this, the error in both positions affects the newly calculated velocity. To determine acceleration and deceleration, the difference of two subsequent velocity measures has to be calculated. This would further increase the error, leading to potentially unreliable data (Buchheit et al., 2014). GPS systems may also base their velocity metrics on changes in the signal frequency due to the movement of the tracker (Doppler shift), which has shown to improve data quality (Schutz and Herren, 2000). Nonetheless, it remains that acceleration measures are a derivative of velocity and the associated errors increase accordingly.

This issue becomes problematic with the recognition that accelerations and decelerations have a great impact on player loading, thus accentuating the benefit of collecting accurate data (Gaudino et al., 2013). Furthermore, actions like jumps would not necessarily lead to a change in position, therefore leading to further underestimations of physical loading with merely positional data (Dalen et al., 2016). Thus, as stated, accelerometers, or inertial measurement units (IMUs), are built within modern wearables (Scott et al., 2016). These unites sample three-dimensional movements at high sampling rates (see Figure 3). Thereby, the addition of this technique led to improvements in the accuracy of positional acceleration data and the description of athlete loading by including jumps or body impacts (Malone et al., 2017). Another added benefit of such high-frequency data, is the possibility to measure gait characteristics, potentially supporting a team's athletics and medical staff (Buchheit and Simpson, 2017).

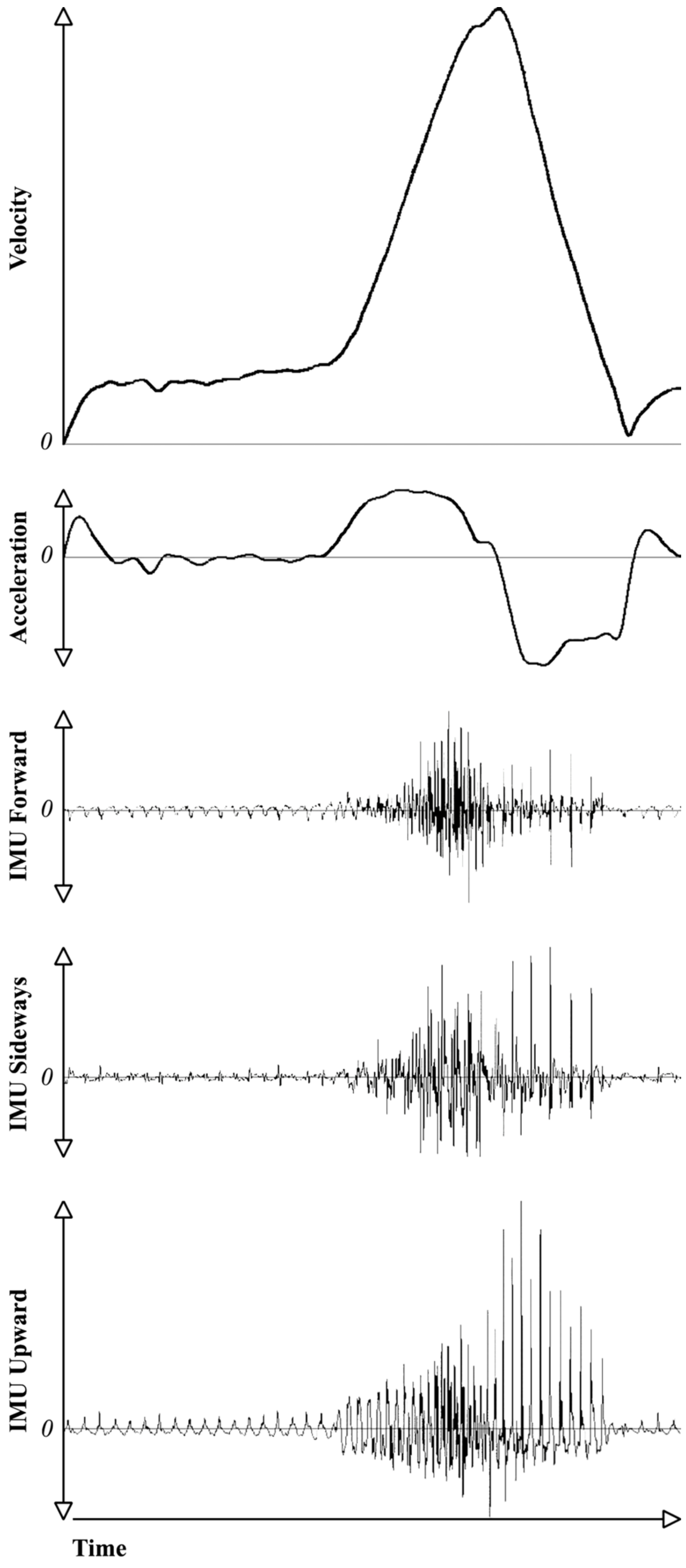

Figure 3. *Example of different types of time-motion data during a straight sprint.*

With all these methods to collect increasingly complex data, one may quickly relate back to the statement in the second paragraph of this chapter: With more data being collected every day, human hands and minds simply do not suffice anymore. The calculation of physical metrics has been taken over by computers and the same goes for the initial processing of the results. Too many parameters are collected for a human to analyse with acceptable speed. Where an analyst can watch one player, game or training session at a time, machines can analyse the quantitative aspects of a multitude of games in a fraction of the time. By incorporating multiple sources of information, more advanced (tactical) metrics may even be developed (Rein and Memmert, 2016). This is where the computerised solutions introduced before prove valuable too, with automated and highly-complex network analyses leading to ground breaking performance metrics. As machines can be set up to learn as they go, models describing overall performance could be continuously updated, to prevent any practitioner from falling behind (see Figure 4).

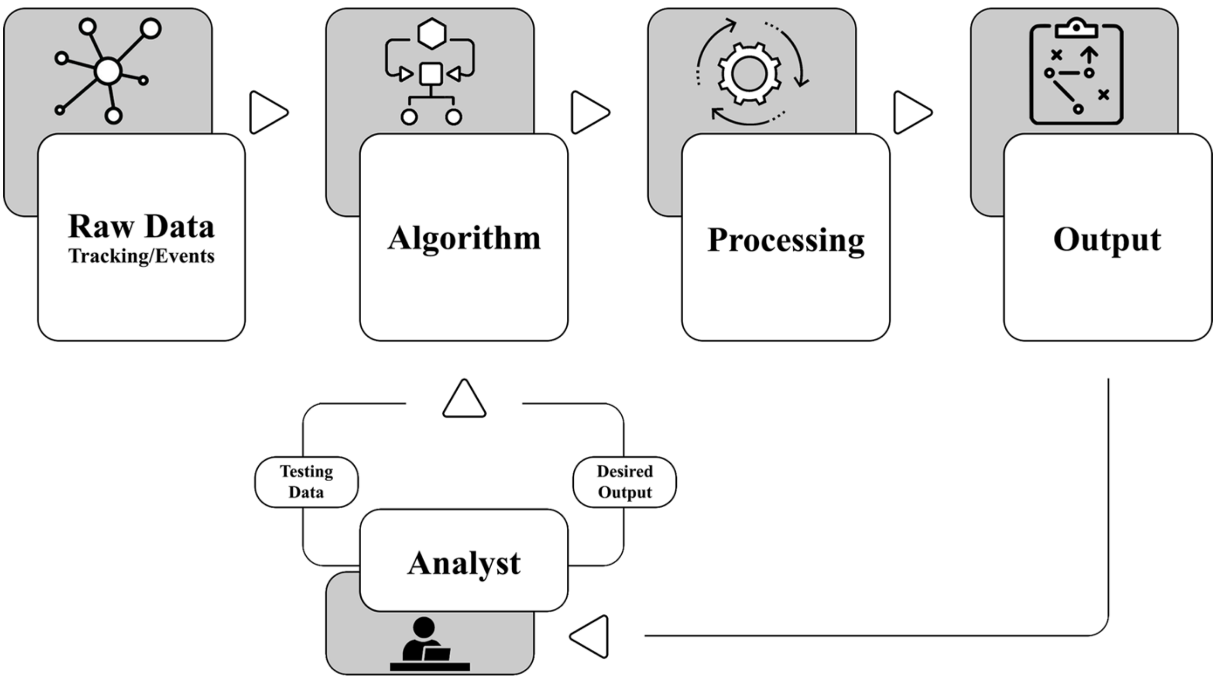

Figure 4. *Graphical representation of a machine learning application with a closed feedback loop in a football environment.*

At the same time, before even considering to claim human input to be redundant, football matches are still played and decided by the players on the pitch. Furthermore, since quantitative match data should be collected accurately, the qualitative conclusions drawn from these analyses should be applied just as accurately and appropriately too. Or to put it in practical terms: match analysis should aid in improving athlete and team performance by adding objectivity to the observations of coaches and practitioners (Mackenzie and Cushion, 2013). That is where match and performance analysts still come into play and provide opportunities for research programmes like the current one.

1.2 Applying match data: Science vs Practice

The previously introduced the methods behind the millions of data entries per match. However, merely collecting does not seem to be the end goal. The raw data is computed into a multitude of metrics and, as mentioned, analysts have to decide on what they want to report on. The scientific community has tested many of these parameters to support practitioners in making substantiated statements. When analysing these studies, it becomes clear that, in general, match data can be separated into three categories: Physical, tactical, and technical parameters (Sarmento et al., 2014). The first classification of metrics is purely based on the previously introduced calculations of positional data. Measures range from distances covered (Di Salvo et al., 2007), to time spent in specific zones of velocity (Schimpchen et al., 2021), or high-intensity accelerations (Ingebrigtsen et al., 2015). Tactical metrics may just as well be based on positional data, with calculations of inter-player distances describing organisational behaviour (Goes et al., 2020). At the same time, notational measures describing tactics can also be found in scientific literature, with metrics ranging from playing formations to possession and passing styles (Gonzalez-Rodenas et al., 2015). Finally, most technical statistics seem based on frequency tables, describing the success rate of metrics like passing or shooting (Harper et al., 2014).

Apart from selecting scientifically sound and useful measures, the context in which they are portrayed can be just as decisive too. Within the current body of literature, many different applications can be found. From overall descriptions of playing characteristics around the globe (Chmura et al., 2017), to comparisons of leagues (Gonzalez-Rodenas et al., 2020), teams (Brito Souza et al., 2019), positions (Bush et al., 2015), and even individual players (Bush et al., 2016). The chosen comparison of selected metrics is often strongly affected by the target population, being scientists, directors, coaches or players. However, in order to make scientifically substantiated judgements in a practical setting, the strength and applicability of the analyses should be known (Hughes and Bartlett, 2002; Mackenzie and Cushion, 2013).

To increase the scientific power and applicability, the majority of the previously introduced studies is based on large datasets and, thereby, describe general characteristics of play. This is interesting when seeking to describe the game itself or the differences between or within particular leagues. However, in practice, it might not be as interesting to know how the average team or player performs. For a practitioner, it is all about the 25 players in the team or the eleven on the pitch and how their performances can be optimised. This would lead to smaller datasets and usually non-generalisable results (Carling et al., 2015). However, these studies may be important showcases of how applied science can be performed and in what directions future academic studies could go. When taking an applied point of origin, large-scale scientific follow-up studies can be designed and performed. Nowadays, with the possibility to create tools that learn over time, a whole new way of calculating specific outcomes has become available (Herold et al., 2019). That said, it was the intent of the current research programme to find practical applications first. This relates to the notion that all previously introduced studies and metrics seem descriptions of quantity. For scientists this is of interest, as large datasets allow for stronger or significant correlations with long-term success (Lago-Ballesteros and Lago-

Peñas, 2010). For a practitioner, long-term success may be the goal, however not necessarily the most effective way for short-term decision making during a match.

At the same time, being successful over a longer period of time, is often worth more for a club than winning a single match. Unless it is an important knock-out tournament or final, like the FIFA World Cup introduced in the very beginning. However, in order to get to such stages where immediate success lingers, a longer period of positive results is usually required. This leads to a pertinent issue within professional football: the longevity of staff, like coaches and directors. At the time of writing, the coaches currently in charge of the teams in the five highest regarded European leagues (England, Germany, Spain, France, and Italy) have been in their positions for one year, five months and 18 days on average (see Figure 5).

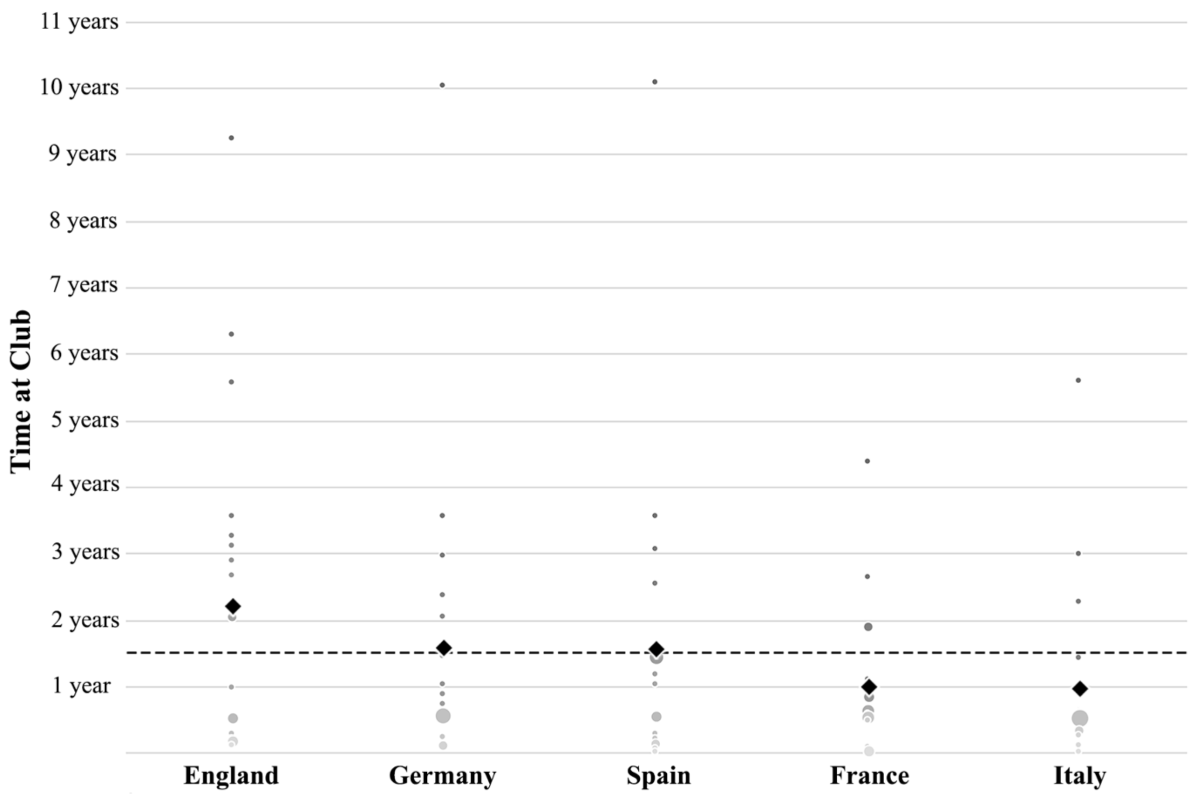

Figure 5. *Time of coaches at their respective clubs in Europe's five highest-regarded leagues. The vertical dashed line represents the overall average and black diamonds the average per league. Larger circles represent more coaches with a similar time in charge.*

Almost two-thirds of all coaches (62%) in these leagues have been in their position for less than a year. This means, coaches usually need some positive short-term results in order to remain in their position and build for a long-term continuation of success. This affects the required analyses too. Where clubs want to see the (long-term) potential of their team and set specific standards, it is the coach who generally has the final say over starting line-ups and tactics. This, in turn, leads to different applications of data. However, with high financial stakes for clubs or investors, the importance of a high standard of objective decision making grows, no matter the intended target being coaches or directors. In order for (football) organisations to function steadily and grow over time, analysis departments seem to become increasingly important. That said, with sport scientists usually directly providing coaches with statistics to optimise their decision making, the current research programme focusses on analyses which can be easily modified, depending on context and coach preferences. This highlights the importance of applied science to be accurate yet flexible, whilst aiming to continuously improving the level of performance.

1.3 What is currently known about the level of performance?

Within the term "performance", an important aspect of the description of match behaviour is introduced. This was already brought to attention by Franks and Goodman over thirty years ago, however remains important to date (Franks and Goodman, 1986). With many studies quantitatively describing the activity or actions of players and teams, a "blank" description of performance is provided. With some of these match parameters being defined as "key performance indicators" (KPIs), it is even hinted, that those metrics are "key" to (future) success (Carling et al., 2008). However, even when related to long-term success, a definite description of quality seems to be lacking. This is especially confusing, since the term "performance" is often (anecdotally) accompanied by adjectives like "good" or "bad", indicating match parameters to be qualitative metrics. Hence, in order to avoid confusion or false interpretations, the term "performance" should (and in the current research programme will) be accompanied by a qualitative or quantitative description.

Whereas these descriptions are not the same, it is both important to know "what" a player did, as well as "how well" he did it. In other words, both the quantitative performance as well as the qualitative level of performance are decisive information for players, coaches, and practitioners (Bradley and Ade, 2018). As introduced before, the quantitative side of (long-term) performance has been covered extensively in the current body of literature. In contrast, although computerised models are getting closer to a contextualised solution, the qualitative side remains more difficult to address (Sarmento et al., 2014).

When taking distance covered as an example of physical "performance", it becomes clear that "more is not always better" (Bradley et al., 2013a). A player could be running at world record pace during a 90-minute match, when he is not in the places where the team needs him to be, there seems to be very little use to his astonishing "performance". As such, this output should definitely be noted and used as evidence for a strongly developed physical capacity, however directly put into context of effectiveness (Di Salvo et al., 2013). Did the player have many ball touches, interceptions or involvements in successful attacking or defensive sequences (Hoppe et al., 2015)?

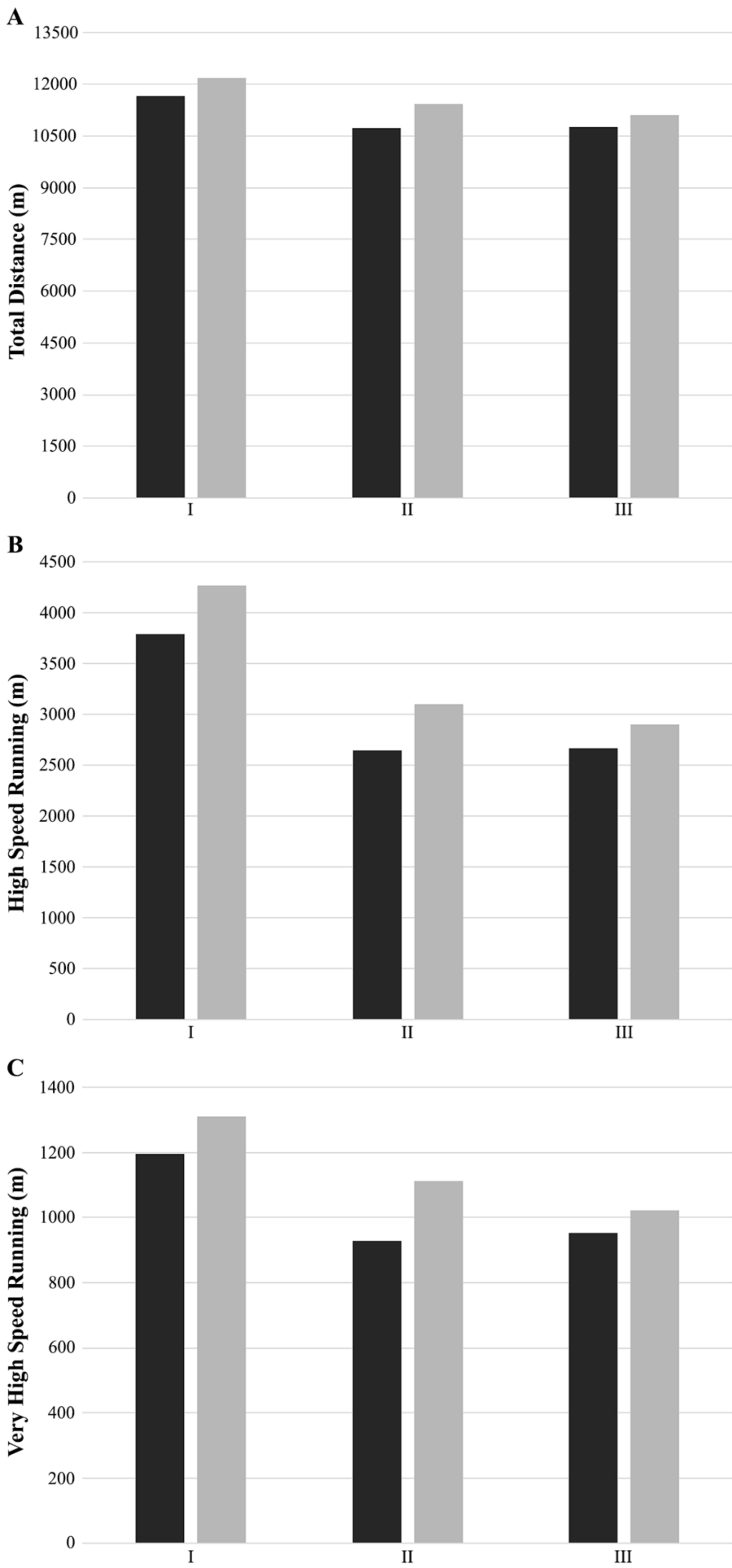

Figure 6. *Running parameters for high (black) and low-performing teams (grey). Reference data from (I) Rampinini et al., 2009, (II) Bradley et al., 2013, and (III) Di Salvo et al., 2013.*

The addition of context changes the perspective and seems like an important aspect of any description of "performance" (Bradley and Ade, 2018). This reasoning can be taken further whilst looking at a tactical parameter like "shots on target". It has been found that successful teams are often characterised by producing more shots on target (Castellano et al., 2012; Lago-Peñas et al., 2010). This is a result expected from dominant and offensive play. However, as already stated by Reep and Benjamin in 1968, the correlation does not seem to be a causation, as it is highly questionable whether a team should aim to have as many shots (on target) as possible (Reep and Benjamin, 1968). This would mean, converting as many ball possessions as quickly as possible into shots, even when that means shots from far away from the opponent's goal. Although a great quantitative performance would be documented with record breaking numbers of shots, when the context of the single events show these attempts led to very little threat, the qualitative performance is not nearly as great. This is, for example, covered in one of the more novel match parameters: xG (expected goals; Anzer and Bauer, 2021; Rathke, 2017; Ruiz et al., 2015). This metric describes the average expectation, calculated from large (international) datasets, of a shot with a specific situational context to be transformed into a goal (Rathke, 2017). Having many shots of "poor quality" in contrast to fewer shots with a higher expectation of returning goals, does not seem to be as attractive anymore (see Figure 7).

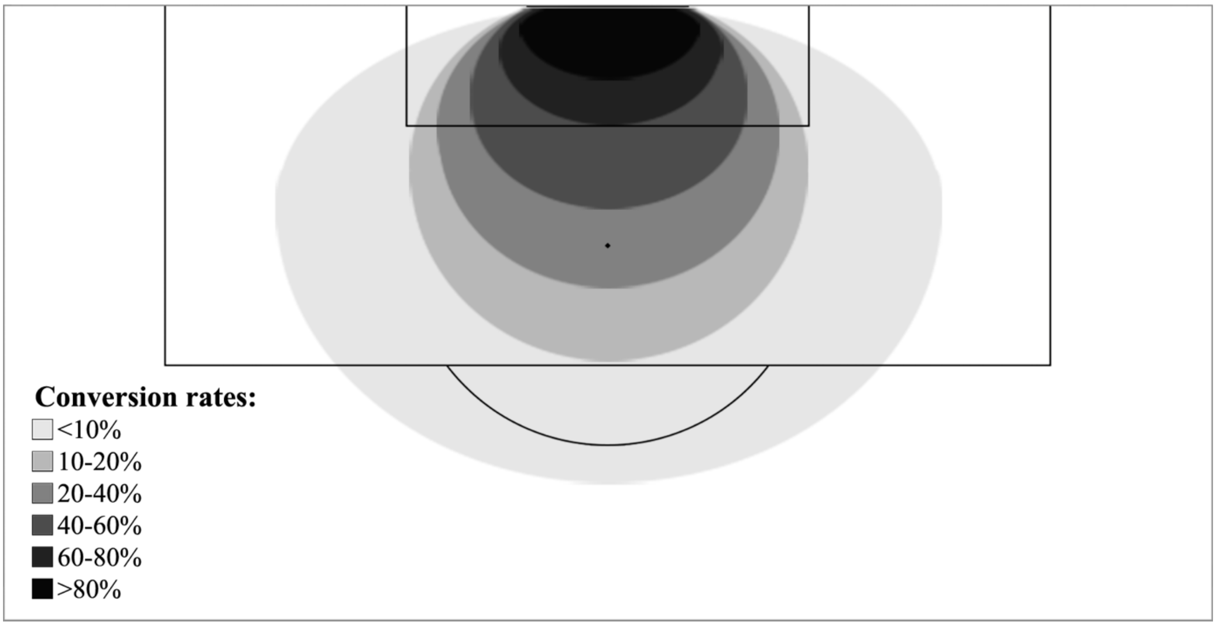

Figure 7. *Simplified graphical representation of goal conversation rates.*

And obviously, without shooting on goal and waiting for that one, unmissable chance, it may become very difficult to score goals and consequently, win matches. However, at the same time, it does not seem to be the case that a team, per definition, should get more shots during a game. It seems they should get better shots, from closer range or with fewer defenders blocking the path to the corners of the goal where goalkeepers would struggle to keep the ball out. In other words, a team should not necessarily aim to get more chances to shoot, they should aim to get more chances to score. In support, it has been put forward that higher quality of shots is more important than the quantity of shots (Anzer and Bauer, 2021).

This opens a simple question: How? It definitely is not as easy as simply getting the objective right. Football is a highly complex and interactive sport with 20 outfield players constantly moving around and half of the players aim to make life hard for the other half (Lames and McGarry, 2007). As such, a straightforward and easy-to-replicate pattern to score a goal seems unlikely to exist. Thus, another approach is warranted. Goals can only be scored by shooting, that remains the case. How well a team is able to do this, comes closer to a qualitative description of achieving an effect whilst in possession of the ball. This train of thought has been started rolling long ago (Pollard and Reep, 1997).

Before going down this path, though, the term "effect" could do with some clarification, as different derivatives are circling the current body of literature. The term itself stems for the Latin "efficere", meaning "to accomplish". From this, "efficacy" describes the power to produce an effect, however in optimal circumstances (Meriam Webster; www.merriam-webster.com). So, to exaggerate, being able to move towards the goal without opponents and outside distractions or obstacles. However, as previously established, with 10 outfield players and a goalkeeper doing everything they can to prevent a team from achieving their goal(s), it seems impossible to speak of efficacy. This is where "effectiveness" comes into place, as this describe the ability to produce an effect in practice. A final derivative, often used and potentially confused, is "efficiency". This, describes the ability to be productive without waste, like a cost-to-benefit ratio. Although desirable and definitely interesting, before one aims to improve a team's or player's efficiency (in shooting or scoring goals), it should first be known how to be effective (in front of goal). By improving the effectiveness, the efficiency automatically comes into play as a final step of being effective more often.

1.4 Why is it important to describe and enhance playing effectiveness?

To support the message of the current research programme, the importance of playing effectiveness is portrayed by the outcomes of the three recent major international football tournaments; the European Championships of 2020 and 2016, as well as the World Cup of 2018. These tournaments, considered to be among the biggest stages in international football, have shown us that most matches were won by teams with the lower percentage of ball possession. When looking at the knock-out phases, where stakes are highest as a loss would lead to direct elimination from the tournament, an interesting trend becomes apparent. During the Euros of 2020, due to the Corona pandemic held in 2021, four out of seven matches that were decided within 90 minutes were won by the team with less ball possession (<50%). During the World Cup of 2018, eight out of 11 matches over 90-minutes were won by the "less-dominant" team and during the Euros of 2016, eight out of 12 matches were won by the team with fewer possession of the ball (see Figure 8). This in contrast to previous findings, describing that successful teams are characterised by a higher dominance in terms of ball possession (Kempe et al., 2014; Lago-Peñas and Dellal, 2010).

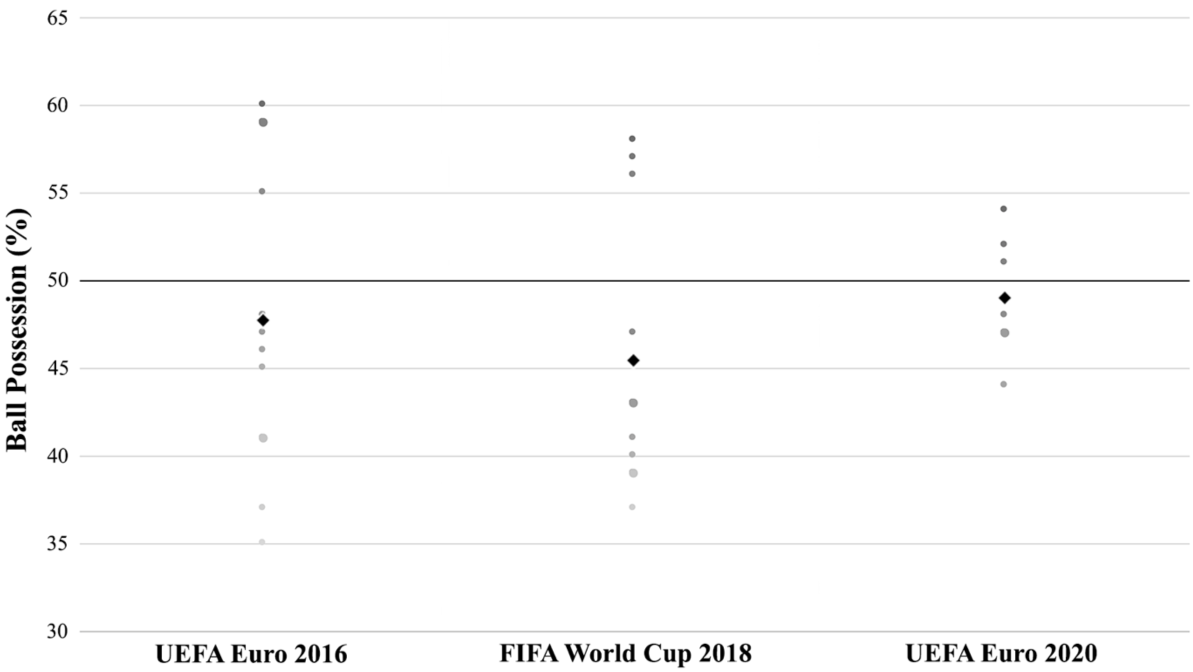

Figure 8. *Average values of ball possession for winning teams in the knock-out stages of the last three major international football tournaments. Black diamonds represent the average per tournament and larger circles represent multiple matches with similar values.*

Theoretically, it is definitely worthwhile to be in possession of the ball, since it becomes very unlikely for the opponent to score a goal at that time. Only own goals could be a counterproductive side-effect from own ball possession, however with 3.0% of all goals scored during the 2020-2021 season in Europe's top five leagues being own goals, it does not seem that this has to be a major consideration whilst playing. Especially whilst own goals mostly occur by unintendingly deflecting shots or crosses from the opponent. On the other hand, although the opponent might not score without control of the ball, being solely dominant does not win matches either (Collet, 2013). Being in possession should result in some sort of effect: Threat in front of the opposing goal.

Especially when the opponent is dominant in possession and one does not have the ball that often, those few instances where the ball is in possession should count. This is where the previously mentioned findings from the international football tournaments and findings from the current body of literature meet: Counter attacks, often a trademark from teams who are not predominantly in possession of the ball, have been found most effective (Sarmento et al., 2018).

This leads to the question of what is important and how this may improve play. If both teams on the pitch are reluctant to have the ball in order to focus on counter attacks, a theoretical stalemate would take place and a scoreless draw would be the most likely outcome. Therefore, utilising the team's strengths whilst benefiting from the opponent's weaknesses could be a more promising tactical plan, as a season full of draws does not seem like a long-lasting recipe for success. A balance in playing style is ultimately required; seeking attacking threat, without becoming overly vulnerable for opponent counter attacks. If opponents are, in fact, better in their possession play, focussing on defensive stability and counter attacks could well be a feasible game plan. However, as said before, seeking a certain amount of ball possession would also limit the possibility of conceding goals. Because independent of one's definition of winning, being "scoring more" or "conceding less" than the opponent, one always has to end up with at least one more goal (being it 1-0 or, for example, 7-6) in order to win. Thus, since at least one goal has to be scored, this reasoning has circled back to being effective, in whatever playing style required by contextual parameters. In order to know what style of play might be optimal for one's team and how to prepare the players for such tactics, general information on playing effectiveness should be gathered. That is where this research programme conclusively comes into play.

1.5 The tactical game plan of the current research programme

Several paths and work flows can be chosen to answer a research question like the one outlined above. As previously introduced, match data has become an enormous collection of numbers and vectors. Looking for the one crucial data point, or that actual key performance indicator, can be perceived as looking for a needle in a haystack. The current research programme took a different route. Instead of trying to converge on that one needle that no one really seems to know what it looks like, this programme chose a divergent focus or, differently put, a top-to-bottom approach. Meaning, the ultimate goal is taken into view and from that, steps backward are made to find out more about the issue at hand. All without losing the initial aim out of sight. Thus, in this case of focussing on attacking effectiveness, it was chosen to start with the question of what characterises the most important feature of attacking effect in football: A goal.

If one ultimately seeks to improve their goal scoring ability and effectiveness, it should be known what makes a shot a goal, other than the fact that it fully crosses the opponent's goal line. Shots can be taken from countless of different positions and contextual scenarios, with the aforementioned opponent outfield players and goalkeeper capable of moving in any way they seem fit. If a certain situational context leads to undoubtedly more goals, creating that situation should be pursued during attacking sequences (Sarmento et al., 2016).

If that is the case (or even when it is not), the characteristics of inter-team interaction may shed light on the follow-up question: What changes in game play lead to a possibility to take a (threatening) shot? In theory, teams are in balance, with both of them starting with 10 outfield players and a goal keeper. If all players would move in perfect synchrony, it would be, again theoretically, impossible to score a goal, since two opposing players would be standing on each other's feet. This indicates the necessity for a certain perturbation of the aforementioned balance, to lose the opponent player and find space to take a shot in the first place.

When this is established, a deeper look into what makes for these changes in balance could be worthwhile. Especially controllable features affecting this capacity to become threatening would be of interest. In practical terms, what player characteristics are apparent in effective attacking sequences and how can these be trained or optimised. Although football remains a team sport and single players can hardly take full control of a match by themselves, individual characteristics are easiest to optimise (Liu et al., 2016). By changing small processes, large effects on the whole operation may be established.

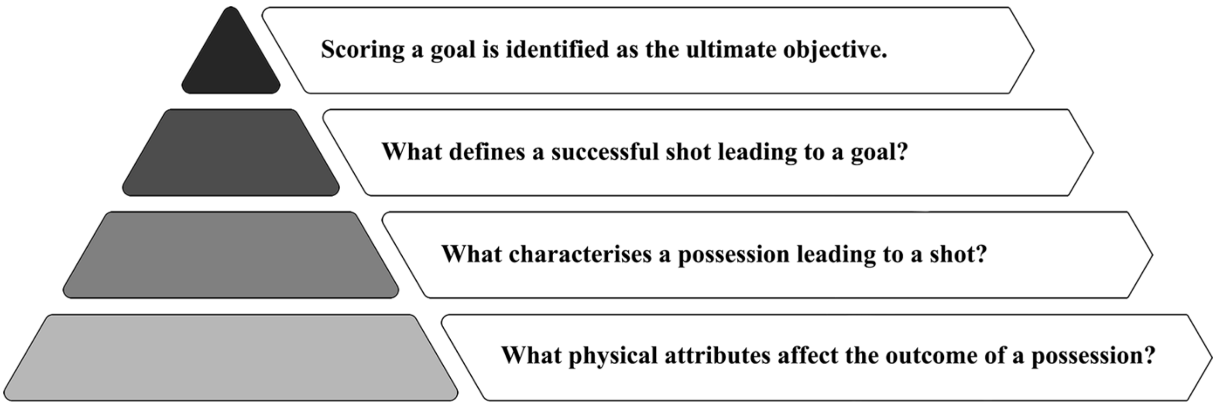

Figure 9. *Graphical presentation of the top-down structure of the current research programme.*

This "tactical plan" would leave the current research programme with implementable guidelines, directly impacting practice. And although most of the previous considerations are explained as offensive trademarks, when knowing what playing styles are most effective, defenders can just as well benefit from this information (Fernandez-Navarro et al., 2016). As such, the current research programme ultimately aimed to assist all players and teams. With these practical guidelines, science and applied practitioners may also be pointed in a practically interesting and worthwhile direction. With this, future scientific studies could be more on-point and easier to implement in practical settings, leaving sport science in general in a better place.

Chapter 2

What factors affect the outcome of goal scoring attempts?

2.1 In search of the unmissable chance

With the structure outlined, creating a scientific base for future success may be initiated. And as introduced, the first step towards improving playing effectiveness is studying that what decides matches: Goals. In order to improve goal scoring abilities, it becomes important to determine what a goal actually distinguishes from other attempts. A player can decide to take a shot from any location or situation he deems fit. Obviously, experience and common knowledge prevents elite players from constantly shooting whenever in range, but knowing what contexts improve the likelihood of actually scoring a goal may still be of great value (Anzer and Bauer, 2021).

In light of that, it seems only logical, that shooting situations without opponents in between the ball and goal line should be sought. However, such an "unmissable chance" is not common and it is highly unlikely that any meaningful conclusions can be drawn from a study researching these events. Furthermore, such reasoning also implies that all opponents or contextual disturbances would impact shooting effectiveness. This potentially undermines the quality of elite players, capable of overcoming obstacles when a goal can be scored. At the same time, player or shooting quality will definitely have an impact on shot outcome too, which is obvious in the scoring rate of penalty kicks, shots under constant circumstances. As already presented by Pollard and Reep in 1997, about 80% of penalty kicks are converted into goals, leading to a xG value of 0.77 at the time of writing (Pollard and Reep, 1997); www.bundesliga.de). If shooting quality would not be a factor in outcome, this should be higher, potentially even approaching 100%, as a theoretical shot at full force into the top corner would be impossible for any goalkeeper to keep out. In data analytics, this is included in the metric "post-shot xG", where the shot placement is considered for the final goal expectancy. Player quality is highlighted by a higher post-shot xG in comparison with pre-shot xG, showing a player is capable of strengthening the goal scoring opportunity (GSO) by their shooting quality and precision. Thus, to collect first information on playing effectiveness, this research programme did not focus on "unmissable chances", however, on chances that are sometimes converted into goals and sometimes missed. This is where contextual factors may come to show and form a guide to future applications.

And where contextual factors might affect the outcome of the shot, the specifics of the outcome (goal or no goal, on or off target) can be studied more closely too. As said, player quality will have an effect on the outcome, but at the same time, even the best players can miss a chance, as implied by the conversion rate of penalty kicks. And although shots that miss the target, cannot lead to goals without external influences, shots down the middle of the goal may not be more effective either (Ali et al., 2007). Obviously, when aiming at the corner, attempts may end up off target, the likelihood of the shot actually resulting in a goal increases too (post-shot xG). As such, shot placement may very well affect the "goal-or-no-goal" outcome too.

Therefore, the first step to improve (the understanding of) attacking and shooting effectiveness was taken by studying the positioning of opponents during multiple shots from the same location. Furthermore, to increase the specificity of shot outcome, a novel description of shot placement was introduced.

2.2 Effects of positional variables on shooting outcome in elite football

The following subchapters appear as published in "Science and Medicine in Football" on the 4th of October 2017. The full publication can be found as an appendix at the end of the thesis.

2.2.1 Methods

Dataset

For the present study, an elite and internationally competing professional team provided their video recordings (25 Hz, 1080P) of all first league matches during the 2011-2012 to 2014-2015 seasons. Since no additional data was collected for the purpose of the present study nor player characteristics were reported, ethical approval was not deemed necessary, however approval was still sought for and granted by the institutional Human Research Ethics Committee (Saarland University) and the study was conducted in accordance with the Declaration of Helsinki.

Shooting situations (scoring attempts by foot) were derived from all home matches played by the participating team during the aforementioned seasons in the Portuguese first league. Headers were not included because when the ball is struck at height, opponents are not as capable of blocking a straight line to the goal, thus requiring the events to be analysed separately (Ruiz et al., 2015). Only home matches were selected to minimise the influence of situational factors related to playing conditions (Pollard and Gómez, 2014). This added up to 62 matches (three seasons with 15 and one season with 17 matches after expansion of the league). From this dataset, only shots taken by the participating team were selected in order to minimise the influence of player quality (Paul et al., 2015). That led to a total of 823 shots.

To minimise variation, only shots that were struck with the ball in a rolling movement were selected for analysis. This means that shots struck mid-air, which require a higher amount of technical skill and arguably may lead to a higher variability, were discarded. Similarly, situations where the attacker attempted a chipped shot were also left out, since they require more skill and goalkeepers behave differently than when they remain close to the goal. Finally, dead-ball situations (penalties, free kicks, corners, and throw-ins) were also discarded due to different defensive organisations (see Figure 10). Since the aim was to study shots from the same position, the resulting 435 shots were analysed for the location the attempt was made from.

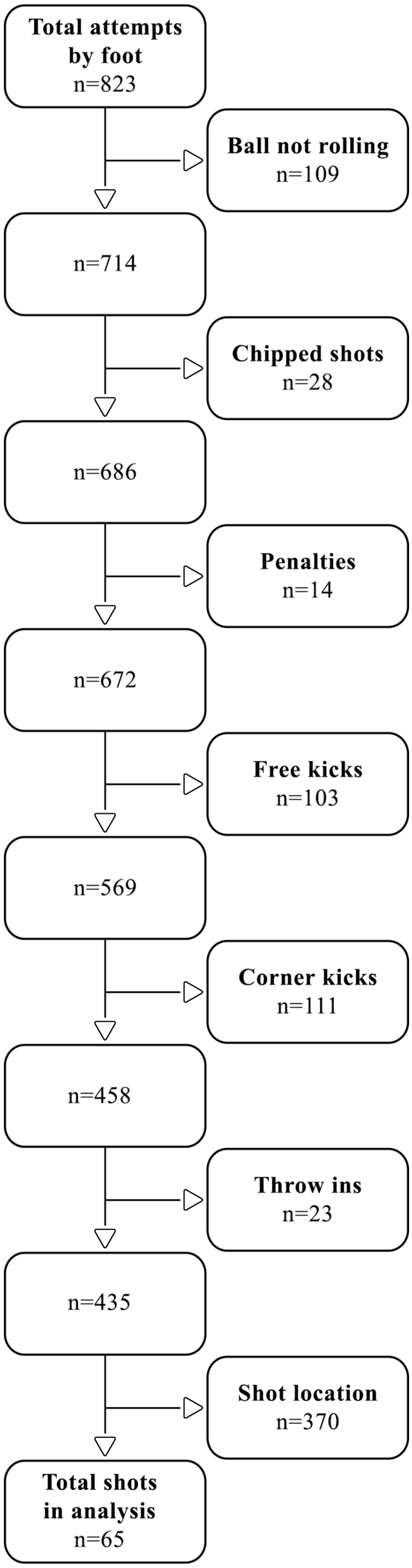

Figure 10. *Selection process of the analysed match events. Starting from all shots (attempts struck by foot) from four seasons of home matches from one specific team, towards those shots fulfilling six additional criteria and selection based on the density of shooting locations.*

Experimental data

Shot and player locations were determined from the video frame at the moment the shot was taken. By using the visible references of the goal and penalty box, the surface was automatically recognised and portrayed in a two-dimensional plane (using Photoshop CC, Adobe, San Jose, CA, USA). Player locations were then manually assigned by placing markers within this flat surface. The accuracy of this technique was determined by comparing the measured width of the goal to the actual dimensions. With an average absolute error of 1.0±0.7% in measuring the goal width, the accuracy is within previously deemed acceptable ranges for positional data (Randers et al., 2010). Furthermore, the reliability of the technique was tested by analysing the frames on separate occasions in a randomised order. A coefficient of variation (CV) of 1.2% (90% confidence limits: 1.0; 1.4%) was found between player positions. With no significant differences between the two measurements ($P=0.13$), the technique seems adequately reliable.

Following the determination of all 435 shooting locations, the density of shots taken within 1.83 m (2 yd) from a specific position was calculated. Based on these densities, three different zones with the highest number of shots (>20) became apparent (Figure 11). The zones, summating to 65 shots, were: 1, from inside the penalty box and on a large angle (n=21 shots); 2, from inside the penalty box and on a small angle (n=24 shots); 3, from outside the penalty box and on a medium angle (n=20 shots).

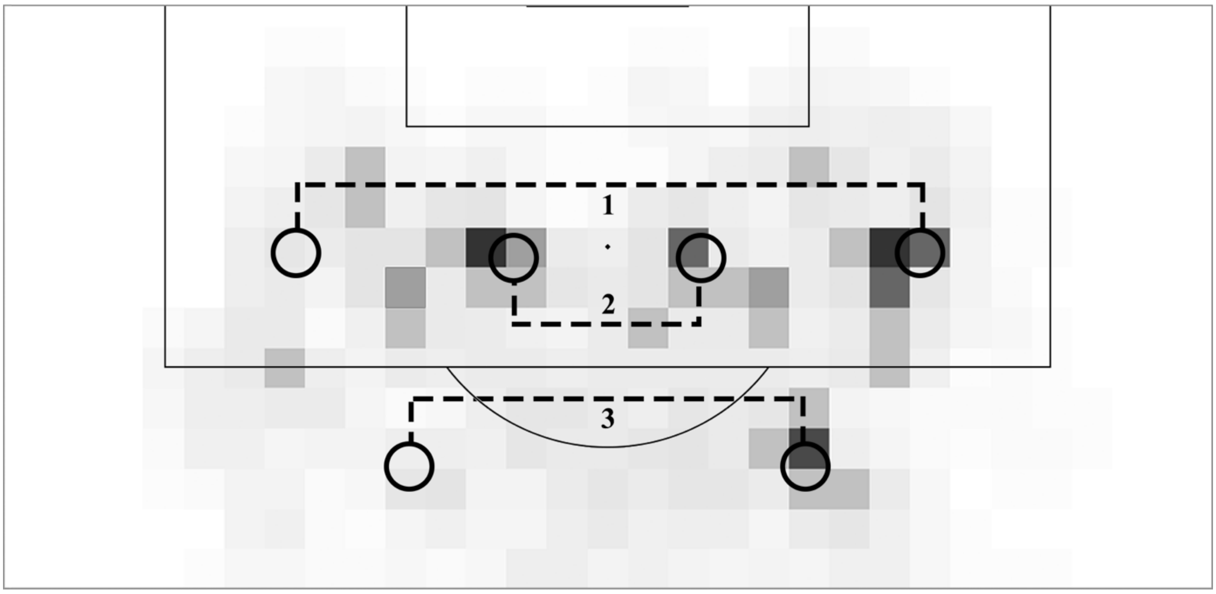

Figure 11. *Selected shooting zones on both sides of the penalty area. Zone 1: 18.47 ± 0.73 m from the centre of the goal and on an angle of 53.1 ± 2.6º; Zone 2: 12.07 ± 1.19 m from the centre of the goal and on an angle of 18.4 ± 6.4º; Zone 3: 22.77 ± 1.19 m from the centre of the goal and on an angle of 23.6 ± 2.9º.*

Each zone was thereafter controlled for the similarity between the collection of shooting locations by calculating Mahalanobis Distances. This analyses the shape and spread of a collection of x and y-variables and the resulting measures can afterwards be analysed for significant deviations from the centre of the shape. No significant outliers were observed in the current dataset. Therefore, all shots were analysed further.

Parameters

All shots were analysed for the following variables at the moment the shot was taken (see Figure 12): the distance from the goalkeeper to the shooting location, the distance from the first defender in line with the shot to the shooting location, the distance from the closest defender (not necessarily in line with the shot) to the shooting location, the number of opponents in line with the shot, and finally the sight of the attacker when taking the shot, computed as the percentage of the goal not blocked by outfield defenders. For these last two variables, opponents were portrayed as 0.91 m-wide circles (1 yd) within the two-dimensional playing surface.

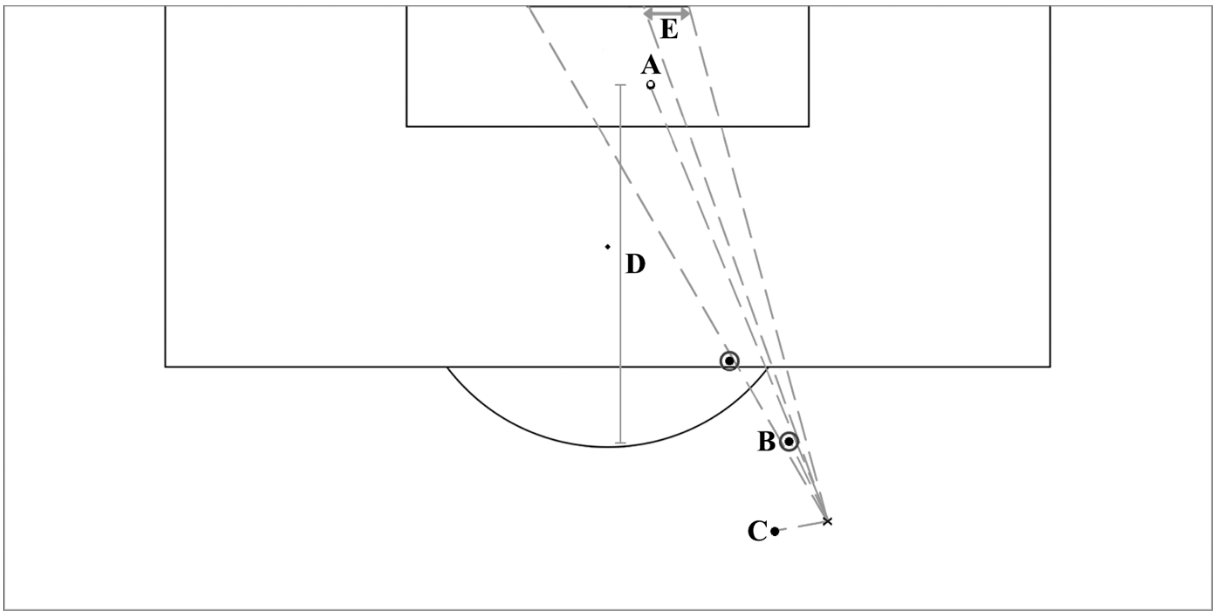

Figure 12. *Example of a shooting situation with all parameters depicted. A: distance of goalkeeper to shooting location (21.3 m); B: distance of first defender in line with the shot (3.3 m); C: distance of closest defender to shooting location (2.7 m); D: opponents in line with the shot and the goal (3); E: sight of goal at the moment of the shot (33%).*

Shooting outcome was calculated in three different fashions: (1) as a measure of being a goal or not, (2) as a measure of being on target (goals and saves) or not, and (3) as a measure of accuracy. This third measure was based on the reasoning that merely shooting on target (for example down the middle of the goal) is not sufficient for success (Ali et al., 2007). The goal was divided into 48 zones with a size of 0.61x0.61 m (2x2 ft), with scores depending on the position of the goalkeeper and the placement of the shot (see Figure 13). The position of the goalkeeper within the frontal representation of the goal was determined by calculating the relative horizontal distance to both goalposts, depending on the distance and angle of the shot. Since placement had to be determined, deflected shots would have been excluded from this analysis. However, none of the included attempts were affected by defenders before their placement could have been estimated.

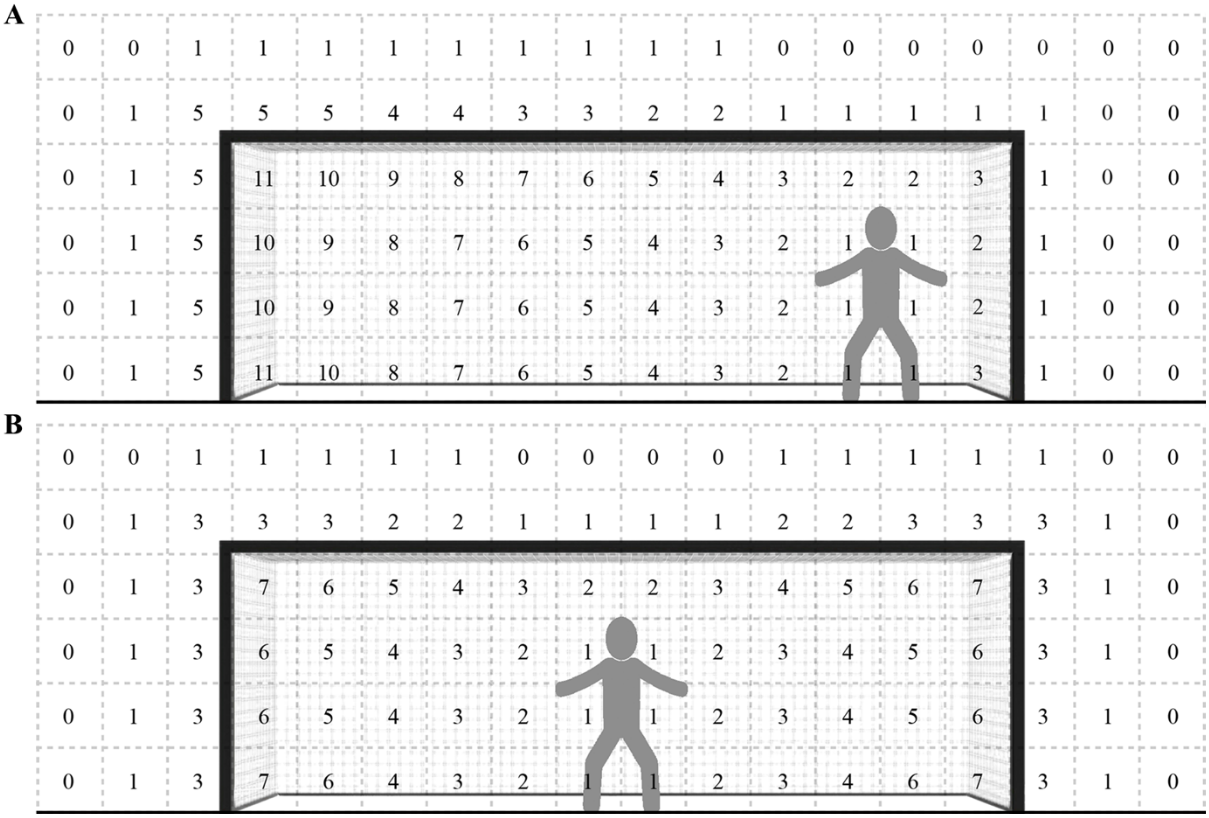

Figure 13. *Two situations describing shooting accuracy as a measure of shooting outcome. For every 0.61 m (2 ft) the ball is placed away from the goalkeeper, an additional point is awarded. Shots placed in the highest quadrant of the goal are scored with an extra point. For shots in the top and bottom corner, another bonus point is awarded. Shots up to 0.61 m wide of the target get half of the score (rounded down) from the most distal zone within the goal. Shots between 0.61 and 1.33 m wide of the target get max 1 point, if the next proximal score was higher than 1.*

Statistical Analysis

Outcomes are displayed, where appropriately, as mean ± standard deviation (SD). Confidence limits (CL, 90%) are reported within square brackets. For all zones, factor analyses using principal component analysis (PCA) were performed to determine whether multiple variables combined could explain more of the variance between the separate shooting situations (Fernandez-Navarro et al., 2016). Bartlett's test of sphericity was used as an indication for sufficient inter-variable correlation. The minimal eigenvalue to separate factors was set at 1 (Kaiser, 1960). Variables with factor loadings greater than [0.7] were analysed further (Comrey and Lee, 2013).

Multiple regression analyses were performed for the collection of variables identified through the factor analyses. Linear regression analyses were also done for all individual variables and shooting accuracy. The magnitude of the Pearson correlation between the variables (r) was assessed by use of the following thresholds: <0.1, trivial; 0.1 to 0.3, small; 0.3 to 0.5, moderate; 0.5 to 0.7, large; 0.7 to 0.9, very large; and 0.9 to 1.0, almost perfect (Hopkins et al., 2009). Furthermore, for the analysis of the outcome as being a goal or on target, the differences for the positional variables between the groups were tested with a non-parametric test of independent samples (Mann-Whitney U Test), since all groups had different sample sizes. For these groups, standardised differences in the means (effect sizes, ES; calculated as the mean group difference divided by the pooled standard deviation) were also determined and qualitatively assessed through the following thresholds: <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; >2.0 very large (Hopkins et al., 2009). When CL (90%) overlapped both positive and negative values, the correlation or effect size was deemed unclear. The significance level was set at P=0.05. SPSS Statistics 24 was used for the execution of all statistical tests (IBM, Chicago, IL, USA).

2.2.2 Results

Factor Analysis

For all zones, the Bartlett's test of sphericity was above 0.5, thereby allowing for the PCA to be performed. The analyses revealed different combinations of variables explaining variance for the three specific zones (see Table 1).

Table 1. *Outcomes of factor analyses for all positional variables and zones.*

	Zone 1		Zone 2		Zone 3
Component	**1**	**2**	**3**	**4**	**5**
DGK	0.633	0.073	0.266	**0.817**	0.044
DFD	0.003	**0.950**	**0.898**	0.022	**0.813**
DCD	0.070	**0.938**	**0.682**	0.370	0.631
OLI	**0.934**	-0.007	-0.312	**0.881**	**-0.910**
SGO	**-0.929**	-0.012	**0.733**	-0.247	**0.894**
% of variance	42.8	35.7	39.5	32.8	53.8

Note: Displayed are those components consisting of variables with strong factor loadings (bold). DGK: distance of goalkeeper to shooting location; DFD: distance of first defender in line with the shot; DCD: distance of closest defender to shooting location; OLI: opponents in line with the shot and the goal; SGO: sight of goal at the moment of the shot.

Table 2. *Outcomes of non-parametric tests of independent samples and effect sizes (ES) for all positional variables between goals (+) and no goals (-) for zone 2.*

	Zone 2			
	+ m±SD	**- m±SD**	**ES [CL]**	**QA**
DGK (m)	8.8±2.9	7.3±3.1	0.47 [-0.23; 1.17]	unclear
DFD (m)	3.9±2.5	4.3±2.8	-0.14 [-0.81; 0.53]	unclear
DCD (m)	2.2±1.1	3.1±2.2	-0.38 [-0.88; 0.11]	unclear
OLI (n)	1.5±0.5	2.1±1.2	**-0.49 [-0.97; -0.01]**	**small**
SGO (%)	73.5±18.8	61.1±25.0	0.47 [-0.13; 1.07]	unclear

Note: Significant and substantial outcomes are highlighted (bold). m±SD = mean ± standard deviation; ES = effect size; CL = confidence limits (90%); QA = qualitative assessment; DGK = distance of goalkeeper to shooting location; DFD = distance of first defender in line with the shot; DCD = distance of closest defender to shooting location; OLI = opponents in line with the shot and the goal; SGO = sight of goal at the moment of the shot.

Goal Scoring

Since merely 2 and 1 goals were part of the dataset for zone 1 and 3, respectively, only zone 2 was included for the analysis of positional variables for the shot outcome as being a goal (8 goals, 16 unsuccessful attempts). The differences between the groups (goals and no goals) are displayed in Table 2.

The multiple regression analysis for the identified factors for zone 2 revealed a non-significant (P=0.37) correlation for component 3. However, a large and significant (r=0.54 [0.25; 0.75], P=0.03) correlation with the outcome of the shot being a goal or not was found for component 4, explaining 29.6% of the variance between these groups.

Shooting on Target

All comparisons between groups and results of linear regressions for all zones are displayed in Table 3.

Of the shots taken from zone 1, 8 were on target and 13 were off target. The multifactorial analysis of component 1 and 2 turned out non-significant (P=0.69 and P=0.51, respectively). From zone 2, 14 shots ended up on target and 10 off target. Component 3 turned out non-significant (P=0.19), however a large correlation with the variables within component 4 and shot outcome was found (r=0.61 [0.33; 0.79], P=0.01). The distance to the goalkeeper and number of opponents in line with the shot explained 36.7% of the variance in shot outcome. Finally, the collection of shots taken from zone 3 consisted of 6 shots on target and 14 shots off target. The single component (5) found for zone 3 turned out non-significant regarding shot outcome (P=0.46).

Table 3. *Outcomes of non-parametric tests of independent samples and effect sizes (ES) for all positional variables between shots on target (+) and off target (-) for all zones.*

		+ m±SD	**- m±SD**	**ES [CL]**	**QA**
Zone 1	**DGK (m)**	14.1±1.9	14.2±1.2	-0.05 [-1.12; 1.02]	unclear
	DFD (m)	3.0±2.0	2.8±1.9	-0.41 [-1.18; 0.36]	unclear
	DCD (m)	2.5±2.1	3.5±1.6	-0.57 [-1.46; 0.32]	unclear
	OLI (n)	1.3±0.5	1.5±0.7	-0.30 [-0.90; 0.30]	unclear
	SGO (%)	93.8±16.1	85.5±22.7	0.34 [-0.27; 0.95]	unclear
Zone 2	**DGK (m)**	7.9±3.2	7.5±3.1	0.11 [-0.55; 0.78]	unclear
	DFD (m)	4.9±3.0	3.2±1.9	0.83 [-0.01; 1.67]	unclear
	DCD (m)	3.0±2.4	2.5±0.9	0.47 [-0.82; 1.77]	unclear
	OLI (n)	1.5±0.5	2.5±1.4	**-0.68 [-1.23; -0.12]**	**moderate**
	SGO (%)	**73.9±19.2***	**53.2±24.4***	**0.77 [0.17; 1.38]**	**moderate**
Zone 3	**DGK (m)**	18.7±2.4	19.5±1.6	-0.47 [-1.73; 0.78]	unclear
	DFD (m)	3.5±0.7	4.6±3.1	-0.34 [-0.81; 0.12]	unclear
	DCD (m)	2.7±1.1	3.0±1.7	-0.15 [-0.78; 0.48]	unclear
	OLI (n)	2.0±0.6	1.7±0.8	0.33 [-0.36; 1.02]	unclear
	SGO (%)	56.0±28.4	76.4±29.9	-0.64 [-1.46; 0.17]	unclear

*Note: Significant and substantial outcomes are highlighted (bold). m±SD = mean ± standard deviation; ES = effect size; CL = confidence limits (90%); QA = qualitative assessment; DGK = distance of goalkeeper to shooting location; DFD = distance of first defender in line with the shot; DCD = distance of closest defender to shooting location; OLI = opponents in line with the shot and the goal; SGO = sight of goal at the moment of the shot; * = significant difference P<0.05.*

Shooting Accuracy

First, the relation between shot outcome, as being a goal or on target, and the calculated measure of shooting accuracy was determined for all 65 shots combined. When comparing groups, goal or no goal and on or off target, shooting accuracy was only significantly higher for shots on target in comparison with those off target (P<0.01; ES: 0.98 [0.58; 1.38]), whereas no significant differences were found for shots on target ending up as a goal or not (P=0.24; ES: -0.42 [-1.09; 0.24]).

Second, regression analyses were performed for all variables and shooting accuracy. The results are presented in Table 4. For all zones, all multifactorial components turned out non-significant (P=0.19-0.92). When taking all zones together, a significant however small correlation between the distance of the closest defender and shooting accuracy was found (r=-0.25 [-0.44; -0.05]; P=0.02).

Table 4. *Correlations between all positional variables and shot placement for all zones.*

	Zone 1		**Zone 2**		**Zone 3**	
	r [CL]	**QA**	**r [CL]**	**QA**	**r [CL]**	**QA**
DGK	0.02 [-0.33; 0.36]	unclear	-0.28 [-0.57; 0.08]	unclear	-0.04 [-0.38; 0.31]	unclear
DFD	-0.22 [-0.52; 0.14]	unclear	-0.01 [-0.35; 0.34]	unclear	-0.02 [-0.36; 0.33]	unclear
DCD	**-0.39 [-0.64; -0.05] ***	**small**	-0.20 [-0.51; 0.15]	unclear	-0.17 [-0.49; 0.19]	unclear
OLI	0.00 [-0.34; 0.34]	unclear	-0.12 [-0.44; 0.24]	unclear	0.14 [-0.21; 0.46]	unclear
SGO	0.18 [-0.18; 0.49]	unclear	0.20 [-0.16; 0.51]	unclear	-0.12 [-0.45; 0.23]	unclear

*Note: Significant and substantial outcomes are highlighted (bold). r = correlation coefficient; CL = confidence limits (90%); QA = qualitative assessment; DGK = distance of goalkeeper to shooting location; DFD = distance of first defender in line with the shot; DCD = distance of closest defender to shooting location; OLI = opponents in line with the shot and the goal; SGO = sight of goal at the moment of the shot; * = significant correlation coefficient P<0.05.*

Individual Analysis

A final exploration was done by comparing different players. From all 65 shots, two players (A and B) had taken most of them with 10 and 9 shots, respectively. Significantly large correlations between shooting accuracy and the distance of the closest defender (r=-0.60 [-0.88; -0.03], P=0.04) and the number of opponents in line with the shot (r=-0.63 [-0.89; -0.06], P=0.04) were found for player B, however not for player A (P=0.20 and P=0.14, respectively).

2.2.3 Discussion

The present study aimed to determine the influence of opponent positioning on shooting outcome. Five positional variables were tested for the outcome of shots taken from the same location, divided into three different zones (see Figure 11). For zone 1, shooting accuracy was affected by the distance of the closest defender applying pressure to the attacker. Interestingly, this relationship describes that shooting accuracy improves with defenders being closer to the shot and forcing the attacker to go into a specific corner. The outcome of shots taken in zone 2 was affected by the distance of the goalkeeper, the number of opponents in line with the shot and the sight of goal. For longer range efforts taken from zone 3, no significant relations with the positional variables were found. The differences in variables affecting shooting outcome shows the importance of incorporating the context of individual match events in their analyses. The likelihood of a shot's success does not merely depend on the position from which it was taken, however at the same time, the influence of opponent positioning was found to change with shooting location and likely other non-tested variables are influential too.

The influence of combinations of positional variables, determined through factor analyses (see Table 1), was determined within the present study too. One of the identified components turned out significantly influential. The combination of the distance of the goalkeeper to the shooting location and the number of opponents in line with the shot was significantly different for the likelihood of shots taken from zone 2 to end up as a goal or on target. This could be interpreted as such, that from a shorter range in front of goal, it is mostly important for the defence to close down on the attacker and make the goal as small as possible (Mitrotasios and Armatas, 2014). Although this seems logical and far from novel information, these findings were only true for one of the three included zones, indicating that coaches and practitioners should not necessarily focus on the same tactical strategies (in defence or attack) with different shooting situations.

The secondary aim of the present study was to test a different measure of shooting performance. The outcome of each attempt was rated for its placement, wherefore a previously used scoring system was adapted (Ali et al., 2007). Since higher ratings could be reached by shooting on target in comparison with shooting off target, the significantly higher scores for the shots on target were to be expected. However, the absence of a significant difference in shot placement between goals and no goals can be deemed more surprising. Although the likelihood of scoring is thought to increase with improved shot placement (Mitrotasios and Armatas, 2014), the results of the present study do not entirely confirm that. A more elaborate study into shot placement, with the inclusion of factors like shot trajectory, being for example straight or curved, might shed more light on the importance of shot placement or shooting style.

The final analysis performed in the present study, involved differences between individual players. Within the complete dataset of 65 shots, two players with totals of 10 and 9 shots, respectively, were best represented. Regression analyses of these shooting situations, across all zones, revealed different relations of opponent positioning with shooting outcome. Thus, although the present study's approach eliminated some inter-individual differences in quality by assuming all players as comparable, the results indicate individual differences. This implies that the analysis of larger collections of shots from individual players might increase the knowledge of shooting efficacy, thereby allowing to improve training or opposition scouting (Ade et al., 2016).

Limitations regarding the limited sample size (n=65) could be raised. However, since the present study aimed to analyse shots from the same position, in order to find out whether shooting outcome is affected by opponent positioning, many of the attempts included within the initial dataset (n=435) had to be discarded. Including different teams might allow for a higher shot density across the pitch, but variability in player quality and team tactics possibly affecting shooting behaviour will increase, too (Paul et al., 2015). Within the present dataset, the influence of different skill levels was minimised by only analysing a single elite team. Thereby it needs to be kept in mind that the presented findings may differ for other populations, however the concept of contextualising match events has been put forward and it can be argued to be of importance. This was also reason for excluding different types of attempts like headers, 1-v-1 situations, or dead-ball situations. One type of attempt was isolated to study the effect of context. Although other events could be of interest too, they arguably require separate analyses due to the different nature of the attempts (Ruiz et al., 2015).

Taken together, with a total amount of variance in shooting outcome ranging from 15-37% being explained by opponent positioning, other factors should be studied to further enhance the understanding of the contextual influence on shooting outcome. For example, since it is known that a straight sprint is most frequently observed prior to a successful shooting attempt, the movement velocity or posture of the shot taker could be of interest for determining shooting efficiency (Faude et al., 2012). From the perspective of coaches and practitioners, knowing in what context one of their players or opponents is most likely to score could strengthen both the offensive and defensive preparation. With modern technology allowing practitioners to measure bodily orientation, such studies should be conducible within the foreseeable future (Buchheit and Simpson, 2017). In general, research into event context appears to be a move forward in analysis specificity from merely describing that successful teams end up with more shots in comparison to less successful teams (Lago-Ballesteros and Lago-Peñas, 2010). The contextualisation of match events in general could prove useful for applied practice, since it describes more closely what happens on the pitch and can thereby be used more precisely in training and preparation (Ade et al., 2016). However, it necessitates more sophisticated analyses.

2.2.4 Conclusion

Adding context to shooting situations, by taking opponent positioning into account, allowed for a more detailed analysis of shooting performance. The influence of such contextual variables did change for different shooting locations on the pitch and for different players. Ultimately, although the positional variables included in the present study were not able to explain all variance in shooting outcome, it has been highlighted that contextual factors should be kept in mind when analysing match events. Aiming to improve one's understanding of why a specific outcome was observed, can lead to a higher efficiency in preparation and play.

Chapter 3

When do attacks develop into goal scoring opportunities?

3.1 Identification of playing patterns affecting attacking effectiveness

Where the previous study showed how the effect of contextual factors on shooting outcome depended on the location of the attempt, it is implied that different situations can be sought during attacking sequences, depending on the strengths and weaknesses of the own and opposing players. Now, following the diverging "tactical plan" of the current programme introduced before, one step back from GSOs has to be taken. In other words, after determining the influence of contextual factors on shooting effectiveness and knowing a little more what type of shooting scenarios should be sought, the question rises how these opportunities came to be in the first place. Or as introduced: What changes in game play lead to a possibility to take a (threatening) shot? This relates to inter-team interaction, since certain events are required to evolve a possession from build-up play to an attacking sequence leading to a GSO (Tenga et al., 2010c). Again, as introduced, synchronised behaviour of both teams would not lead to any shots, let alone goals. As such, a change in interaction is required, which has been confirmed since proposed in 2010 (Moura et al., 2016).

This synchronised interaction (balance) exists, in theory, simply because teams start a match with the same number of players. An intact balance, again theoretically, prevents any player from taking a shot as there is no space between attackers and defenders (Tenga et al., 2010a). Tactical formations can affect this balance, by lining up a different number of defenders in relation to the opposing attackers. This would consequently free up space somewhere on the pitch. However, whilst looking at attacking effectiveness, it is very common to see a line up where a team starts with more defenders than the opposing team starts with attackers (Bradley et al., 2011). Thus, even disturbing the inter-player balance of one attacker and his direct opponent may not be enough to create space for a shot as potentially another "free" defender, covering space, can take up the role as new opponent (Tenga et al., 2010b). As such, chain events, involving multiple players, may be required to open up space for a GSO (Moura et al., 2016). Furthermore, the previous chapter already highlighted that space can be a deciding factor in shot outcome.

Therefore, since players need to look for space to become effective in front of goal, it seems important to know how inter-team balance develops during an attack and what actions lead to a deciding perturbation. Depending on a combination of qualitative and quantitative parameters taken from coaching guidelines, a description of defensive balance has been established before (Tenga et al., 2010a). It was then found, that attacks against imbalanced defences were more threatening than attacks against balanced defences, just as theory predicted and confirmed since (Lago-Ballesteros et al., 2012; Tenga et al., 2010b). With such knowledge, it becomes interesting to know whether certain types of play are more capable to perturb the balance within the opponent's defensive organisation.

By knowing when the balance gets disturbed and if patterns exist for certain teams, a new multidimensional and more flexible type of analysis would become available. Apart from having to rely on fixed moments in a sequence (like a shot, assist, or zone entry), moments of a team's vulnerability may be exposed, which may be sought more easily during attacking sequences. At the same time, such a qualitative approach may increase subjectivity and reduce the reliability of analyses (Tenga et al., 2009). Therefore, the applicability of such an approach needs to be tested. This is where the following study comes into place, exploring the reliability of observations of defensive balance. By comparing observational methods based on qualitative ratings and a single subjective assessment by experts, typical styles of play affecting balance may become apparent.

3.2 Exploring defensive balance before goal scoring opportunities in football

The following subchapters formed the basis for the compressed publication in "Sport Performance and Science Reports" on the 23rd of June 2019. This publication can be found as an appendix at the end of the thesis.

3.2.1 Methods

Design

To understand how inter-team balance developed during attacking sequences, expert participants completed two experimental trials, where defensive balance was rated in a second-by-second fashion. Additional characteristics were recorded afterwards to describe the progression of play and define the concept from different scientific angles.

Participants

Eight observers (age: 36±11 yrs; experience with match analysis: 9±6 yrs) participated in the present study. The observers were match analysts or coaches, holding at least a B-level licence from the European Football Association (UEFA). Furthermore, participants had 20±8 yrs of playing experience, ensuring a basic level of understanding of tactics in football. The participants provided informed consent before the first trial. The study was ethically approved by the local Human Research Ethics Committee and performed according to the Declaration of Helsinki.

Measures

In total, 14 sequences ending in a GSO were incorporated within the present study. The events were derived from multiple matches played by the German national team in preparation of the UEFA European Championships 2016. Match analysis, including positional data and notational coding, was provided by Amisco Pro® (Di Salvo et al., 2006).

The events were selected to create a diverse dataset with various build-ups to the GSOs. Five sequences were included in the familiarisation trial and nine sequences were included in the experimental trials. Those nine events were counterbalanced for two parameters. First, the outcome was classified as a goal, an attempt on target (being saved by the goalkeeper or defender in line with the ball and the goal), or an attempt off target. Second, the possession type was characterised as a counter attack (where the defensive team was unorganised and passes were mainly directed forwards), a direct passing attack (where the defensive team was organised and passes were mainly directed forwards) or an elaborate passing attack (where the defensive team was organised and passes were directed forwards, sideways and backwards; (Lago-Ballesteros et al., 2012).

Each event had to meet certain criteria: (1) the ball had to reach the goal line, goalkeeper or a final defender, what means that blocked attempts were interpreted as adequate defending; (2) the event did not originate from a set piece on the attacking half within the final 20s before the actual attempt; (3) the distance from the ball to the goal at the moment of the attempt should have been clear or no longer than 25m to ensure a substantial GSO. For every event, wide-view video footage (Scouting Feed®; see Figure 14), wherein all outfield players were constantly in sight, was used. The events were cut at the moment the ball was last struck and started with the recovery of possession or after maximally 20 seconds of possession. Hereby, the outcome was not identifiable to the observers.

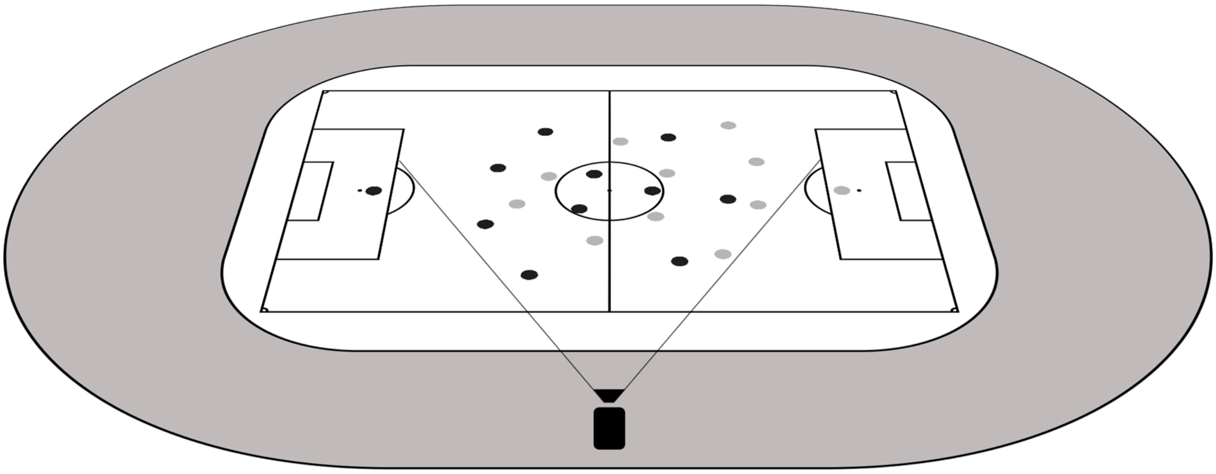

Figure 14. *Graphical representation of the wide-view tactical perspective.*

Independent of the observers' experience, a general description of defensive balance was provided. Several examples of situations where the aspects of defensive balance, introduced by Tenga and colleagues, were apparent, were highlighted in video sequences (Tenga et al., 2010a). Afterwards, a familiarisation trial consisting of five pre-selected match events was performed to ensure full understanding of the concept and procedures.

The experimental phase of the present study consisted of two trials. During both occasions, the remaining nine match events were shown in a randomised order. Hereby, the inter- and intra-observer reliability of the protocol could be determined. Seven to 14 days interspersed both trials, to prevent recognition of the events and recollection of the ratings. The ratings given during the first trial were not available to the participants during the second trial.

The participants were first shown the full match event, to become familiar with the progression of play, as no action was required. Afterwards, the events were shown in 1-second bouts with a self-controlled pause in between. For every second of all match events, a rating had to be given on a 5-point Likert scale, whereby a score of "1" corresponded with "very poor balance", "2" with "poor balance", "3" with "fair balance", "4" with "good balance", and ultimately "5" with "very good balance". This approach was selected to allow for the development of (im)balance to be determined (see Figure 15). After all seconds were rated, the full event was displayed once more, where after the observers were asked what point in time they deemed crucial for the occurrence of the GSO (SEC). Finally, the most important reasons for the occurrence of the GSO were asked from an offensive (OFF) and defensive (DEF) standpoint. The offensive options were (1) a direct pass to a teammate, (2) a pass into space, (3) a run with the ball, (4) a run without the ball, and (5) none/other. The defensive options were errors with (1) an attempted interception, (2) pressure, (3) backup, (4) cover, and (5) none/other.

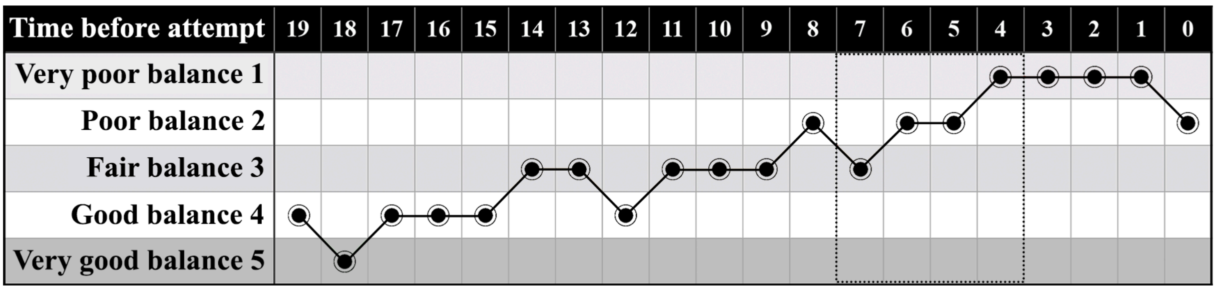

Figure 15. *Example of a second-by-second rating. The most detrimental change over four ratings is highlighted in the dotted box.*

Since changes in ratings are arguably more important than the actual ratings themselves, the slope over every four consecutive ratings of defensive balance was calculated to analyse the rating pattern (SLP). Furthermore, the ratings were natural log-transformed in order to stress the importance of changes in the lower scoring ranges. This followed from the assumption that a change from bad (2) to very bad (1) is more detrimental to a team's balance than a change from very good (5) to good (4).

Since the duration of the match events differed, SEC and SLP were computed as continuous time variables counting backwards from the moment of the actual attempt. Thus, both measures described the time before the attempt where defensive balance was deemed to be lost (in seconds).

Statistical Analysis

Outcomes are displayed, where appropriately, as mean ± SD. The difference between the two measures of defensive balance (SEC and SLP) was determined through paired-samples T-Tests. Cohen's Kappas (K) were calculated to determine the magnitude of the reliability of all variables (Landis and Koch, 1977). A quadratic weighting was chosen to emphasize the importance of ratings being close together. For the reasons why the GSOs occurred, a non-weighted approach was chosen, since the options had no relationship to each other. Paired-samples T-Tests were performed to determine the significance in different Kappa values within observers. Independent samples T-Tests were performed to determine the differences between raw scores. Whenever the criteria for normal distribution were not met, a non-parametric Wilcoxon test was performed. The level of significance was set at 0.05 and all tests were executed in SPSS Statistics 24.0 (IBM, Chicago, IL, USA).

3.2.2 Results

Agreement of Measures

No significant differences between the SEC and SLP were found (P=0.46 in trial 1 and P=0.64 in trial 2). Within both trials, defensive balance was found to be lost on average 4.8±1.2 s before the attempt according to SEC and 5.1±0.9 s before the attempt according to SLP (P=0.42).

Inter-Rater Reliability

The raw ratings of defensive balance showed a moderate agreement between observers (K=0.52). The computation of these ratings into SLP led to a similar moderate between-observer agreement (K=0.47). Another moderate agreement between observers was found for SEC (K=0.50). Finally, when analysing the reasons for the occurrence of the GSO, slight between-observer agreements were found for OFF and DEF (K=0.17 and K=0.11, respectively).

Intra-Rater Reliability

Since the same match events were shown in both trials, the within-observer stability of the variables could be measured. For the raw ratings of defensive balance, a substantial within-subject agreement was found (K=0.74). Again, similar agreements were found for SLP and SEC (K=0.72 and K=0.79, respectively). For the reasoning, why the GSOs occurred, the observers showed moderate intra-agreement (K=0.53 for OFF and K=0.40 for DEF). The experience of the observers (years active as coach or analyst) did not significantly affect any of the agreements (P=0.06-0.50).

Situational Variables

Observers showed lower agreements in SEC during counter attacks and elaborate build up in comparison with direct passing build up (P=0.03 and P=0.01, respectively). Also, a higher between-observer agreement was found for those events that led to a goal (which the observers were unaware to), in comparison with those attempts that were saved or off target (P=0.04 and P=0.03, respectively).

3.2.3 Discussion

The present study aimed to determine whether defensive balance in elite football can be reliably distinguished and rated by expert observers. Through the scoring of attacking sequences in a second-by-second fashion, the development of (im)balance within defensive structures was measured. The most detrimental change within the ratings was then compared with the selection of the most decisive second by the observers. The former showed that balance was lost 5.1±0.9 s before the attempt, where the latter came to an average of 4.8±1.2 s. The lack of a significant difference between the methods (P=0.42), in combination with substantial within-observer agreements for both measures, indicates that practitioners are capable of reliably selecting the moment they, individually, hold crucial during an attacking sequence.

At the same time, mere moderate between-observer agreements were found for the development of balance. This indicates that individuals seem to have different interpretations of the constructs involved in defensive balance, most likely due to the multidimensional nature of the concept (Tenga et al., 2010a). Along with unsubstantial agreements between the reasons why the GSOs occurred, the qualitative approach of the current study does not seem to be suitable to determine what (typical) constellations of player and ball positioning are most effective in disturbing an opponent's organisation and thus creating GSOs.

As the current qualitative approach fails to determine which types of play affect team balance, it is questionable whether the proposed parameters of balance (pressure, backup, and cover) are two dimensional (e.g. good or bad). For example, it has been put forward that tight defensive pressure, in combination with other parameters, adds to a balanced defence and vice versa (Tenga et al., 2010a). Furthermore, ball interceptions, which require high pressure, were also found to be linked with team success (Vogelbein et al., 2014). Likewise, the current study revealed that experts deemed mistakes in defensive pressure most often to be crucial (43% of the time). Thus, applying pressure by defensive players seems to influence the defensive performance. However, ball interceptions require a move towards the upcoming attacker, thereby mirroring its run towards goal. By failing to succeed in intercepting possession, space opens up for the attack. This, in turn, agrees with the results from Moura and colleagues, where they reported movements in opposite directions (anti-phase coordination) by the defensive and attacking teams before GSOs (Moura et al., 2016). As such, high pressure, when not backed up by teammates (Tenga et al., 2010a), may even be detrimental to a balanced defence, when the attacker is able to evade the first defender.

The space for the attacking team seems to be a generally important aspect within playing effectiveness. Multiple studies have found that counter attacks and direct passing attacks are more effective in comparison with elaborate build ups, especially when defensive balance was disturbed (Lago-Ballesteros et al., 2012; Sarmento et al., 2018; Tenga et al., 2010b). This can be explained by the fact that attackers have more space to run into when there are fewer defenders ahead (Lago-Ballesteros et al., 2012). In other words, when inter-team balance is disturbed, attacks seem to be more effective. This is also apparent in the fact that higher agreements were found in the current study for when the GSO ended in a goal, although the observers were unaware of the outcome. This implies that the severity of the disturbance in balance tends to be greater and thereby less disputable. Thus, it can again be argued that defensive balance indeed affects attacking efficacy (Tenga et al., 2010a).

The different possible interpretations of Cohen's Kappa have to be acknowledged. Within the current study, the qualitative assessments from Landis and Koch have been applied (Landis and Koch, 1977). Although different guidelines and techniques have been proposed, the currently used analysis is still believed to form an adequate description of agreement (Vach, 2005). Furthermore, results may be compared more easily, since the assessments are often used. In the end, it comes down to the personal interpretation of the Kappa scores, whether for example 0.6 or 0.8 is taken as a minimal requirement of good agreement (Vach, 2005). The moderate inter-observer agreements within the present study are thereby questioned, however with five out of eight intra-observer agreements for SEC being 0.85 and higher, that reliability seems present. This may also be explained by the fact that SEC only involved a single observation, what minimises possible variance in comparison with a collection of observations for SLP.

Another possible factor expected to cause variance in the current measurements was the experience of the observers. However, no significant relationships between any type of experience (with analysis, coaching, or actively playing) and intra-observer agreements were found. The correlation variable closest to significance (coaching experience and SLP; P=0.06) was in fact for a negative correlation, thereby describing that observers with more experience tended to have a lower agreement within SLP scores in trial 1 and 2. All other significance levels were far away from the set 0.05 threshold. Future research should be performed to determine whether experience is not a factor or the current methodology did not warrant reliable results (Andersson et al., 2005). Another limitation relates to the fact that the present results come from a limited dataset, with eight observers rating nine different clips. Future studies could aim to replicate similar approaches with potentially more experts rate more sequences. However, even with such a small sample size, substantial agreements and significant differences were found.

Several more future applications can be proposed. From a scientific point of view, the qualitative interpretation of defensive balance composed in the present study could be linked with the quantitative approach of Moura and colleagues (Moura et al., 2016). By studying the positional context at the moment experts describe a change in balance, potentially an objective determination of the time points when balance is lost can be established (Gréhaigne et al., 2001). The objectification of deciding patterns of play, which the current qualitative study turned out to be unable to do, could aid science and practice in the future (Link et al., 2016). Such research would be in line with studies that found correlations of specific types of play and attacking success, however then focussing on disturbing a team's balance, independent of leading to a GSO (Sarmento et al., 2018).

From a practical point of view, merely an individualised approach of the current methods seems possible. Since no meaningful between-observer agreements were found, only the substantial intra-observer agreements allow for an individual application. The analysis of the type of play leading up to the loss of balance for specific opponents or the own team may enhance analysis specificity in comparison with studying fixed moments in time like the shot, assist or turnover in possession (Tenga et al., 2010c). By studying which teams or players are capable of disturbing the balance within an opponent's defences, training and preparation towards attacking and defensive effectiveness may be optimised.

3.2.4 Conclusion

Taken together, the present study found that observers, experienced with playing tactics, were able to provide similar ratings of the loss of defensive balance leading up to GSOs during two separate trials. The between-observer differences highlight the multidimensional nature of the sport and the requirement of more detailed studies in the future. Different Kappa scores were found for distinctive attacking outcomes and styles of possession, emphasising that the severity of the loss of balance can differ and affect playing effectiveness. Ultimately, the concept of defensive balance seems a promising and worthwhile approach for future scientific work and applied practice, in which the current qualitative analysis of single expert observations may be useful.

Chapter 4

Measuring physical characteristics

4.1 Developing new ways

Although the previous study did not find specific types of play to be more detrimental to inter-team balance than others, it was highlighted that the severity of the changes in balance were related to the outcome of the attack. This finding seems to describe certain changes in player behaviour during promising attacking sequences. Since tactical play was not found to have a clear effect, player characteristics may be put to the (scientific) test. If certain physical parameters are more distinct during attacks with a certain outcome, playing effectiveness and player profiling may be enhanced.

In order to test such a hypothesis, detailed tactical information is required along with complete, second-by-second, time-motion data. This is where issues may arise for science and practitioners. Elite teams are often not eager to share or publish in-dept information regarding their playing style or other tactics. Performing such studies would be easier to accomplish with participants from sub-elite levels. However, sub-elite or amateur teams often do not have the financial capabilities to invest in accurate tracking solutions, providing time-motion data. Solutions that present lower financial burdens are mostly of inferior quality, potentially leading to unreliable results. Since most studies presenting physical data are performed with elite or professional teams, the tracking systems used are aimed at this market too (Trewin, 2017). As such, validation studies of merely these high-end solutions can be found in the current body of literature (Beato et al., 2018; Varley et al., 2017).

Thus, although sub-elite teams may be willing to participate in studies where tactical data is collected and shared, providing reliable or even any time-motion data can be regarded as problematic. As such, new developments have been made, with tracking systems aimed for sub-elite or individual users being released to the public. This would allow for a higher standard of scientific practice in a greater range of teams, potentially improving the level of play throughout the sport. Furthermore, if more sub-elite or amateur teams can afford to invest in a tracking system, more studies, with increased sample sizes may be performed (Scott et al., 2016). This, in turn, may lead to novel insights and developments, which could even assist practitioners in elite environments.

Therefore, before sub-elite teams may be recruited to study player characteristics during different tactical playing styles and the actions leading up to different outcomes of attacking play, the accuracy of the collected time-motion data needs to be tested (Malone et al., 2017). This is of particular importance considering that low-cost solutions operate at lower frequencies and errors were still found to become larger with increasing velocities, despite a greater overall precision for higher sampling rates (Rampinini et al., 2015; Scott et al., 2016). This leads to the following study, aimed to determine the accuracy of a newly designed and low-cost GPS system. Both time-motion and reference data for distance and velocity were recorded during established football-specific movements.

4.2 The Accuracy of a Low-Cost GPS System during Football-Specific Movements

The following subchapters appear as published in the "Journal of Sports Science and Medicine" on the 1st of March 2021. The full publication can be found as an appendix at the end of the thesis.

4.2.1 Methods

Design

Similar to previous studies (Coutts and Duffield, 2010; Hoppe et al., 2018), a continuous protocol including football-specific movements and two criterion measures was performed to analyse the validity and reliability of the collected time-motion data from a GPS system.

Participants

Sixteen male football players (24 ± 3 years, 1.80 ± 0.03 m, 78 ± 4 kg) playing for a professional fourth division team, participated in the study and provided informed consent after the risks and benefits of the study had been explained. The study was ethically approved by the local Human Research Ethics Committee (Ärztekammer Saarland; ref: 23/17) and performed according to the Declaration of Helsinki.

Procedures

The complete study consisted of three different trials. First, a familiarisation trial was performed, followed by two experimental trials to measure validity and reliability. The experimental trials were separated by 14 days, however normal training continued in between.

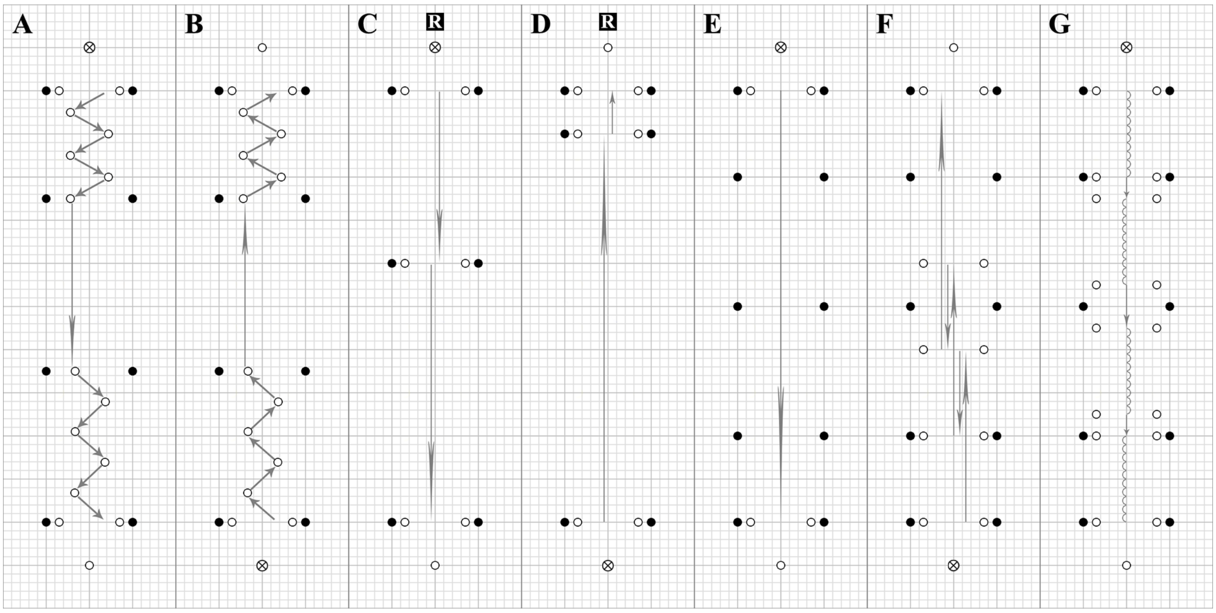

Figure 16. *Overview of the validation protocol, involving seven different movements executed back and forth over a 60- m course of which the first and last 5 m are covered walking. A: sideways shuffling with five 60-degree and five 90- degree turns; B: diagonal jogging with five 90-degree and five 60-degree turns; C: 20 m maximal acceleration and 30 m gradual deceleration; D: 45 m gradual acceleration with 5 m maximal deceleration; E: 50 m backwards jogging; F: 90 m shuttle running with six 180-degree turns; G: four 10 m sideways skipping ladders while alternating side facing and total of 10 m walking in between. Black dots represent timing gates, white dots cornering poles or gates, crossed dots start points, black squares with "R" the radar gun and grey lines the movement direction.*

The protocol consisted of seven types of movements over a 60 m course (see Figure 16), which proportionally simulated the activity previously observed during competitive football, both in style as well as the intensity of locomotion (see Table 5; (Bloomfield et al., 2007). The movements of the experimental trials were interspersed by short periods of static behaviour (5-10 s). These were included to enhance the ecologically validity of the protocol, as players are stationary for approximately 5% of playing time (Bloomfield et al., 2007). Each trial involved the continuous execution of the different movements and since some involved cornering or turns, a total distance of 500 m was covered per session (see Table 5). To ensure participants followed the planned course accurately, vertical pole gates and slalom poles were used which the participants had to cross and round as closely as possible.

Table 5. *Distribution of distances covered for various styles of locomotion during seven types of movements.*

	A	B	C	D	E	F	G	Total
Walking	20	20	10	10	5	5	5	75
Jogging		50		15	50	40		155
Running				25		25		50
Sprinting			20	5				25
Skipping							40	40
Shuffling	50							50
Other	10	10	30	5	5	30	15	105
Total	80	80	60	60	60	100	60	500

Note: Distances are reported in m. Movements: A=sideways shuffling with five 60-degree and five 90-degree turns; B=diagonal jogging with five 90-degree and five 60-degree turns; C=20 m maximal acceleration; D=45 m gradual acceleration with maximal deceleration; E=50 m backwards jogging; F=shuttle running with six 180-degree turns; G=four 10 m sideways skipping ladders while alternating side facing.

Measurements

The GPS devices provided by the manufacturer (TT01, Tracktics GmbH, Hofheim, Germany; firmware version 1.7) collected positional data at a frequency of 5 Hz and triaxial accelerometer data at 200 Hz. Initially, the raw velocity data from the GPS-chip was computed onboard using two methods: positional differentiation and the Doppler-shift method. The final data describing distance, velocity and acceleration followed from the integration of input provided by all onboard components, such as the GPS-chip and accelerometer. These automated computations had been designed to continuously determine the most likely movement trajectory, depending on the quality of the available data.

The GPS tracker was designed to be worn centred on the lower abdomen, within a specifically designed belt below the elastic band of the shorts (see Figure 17A and 17B). The belt moves the tracker in a forward-tilted position, optimising antenna functionality (see Figure 17C). Each participant was assigned a personal device, which was used throughout the study in order to minimise inter-unit variability. The devices were activated in advance, to ensure a sufficient satellite fix, indicated by a LED light on the devices, prior to each trial.

The average number of satellites connected to the devices during the first trial was 13.3 ± 1.2 and for the second trial 13.5 ± 1.3. Furthermore, the average horizontal dilution of precision (HDOP), which describes the arrangement of the connected satellites across the sky, was 0.78 ± 0.05 and 0.75 ± 0.06 for the first and second trial, respectively. As it has been described that a connection to more than six satellites and HDOP values below 1 describe ideal conditions, the collected data was deemed suitable for analysis (Malone et al., 2017). As the GPS devices created encrypted data files, the time series of distance and velocity data were provided by the manufacturer, who was blinded to the testing protocol. These time series consisted of computed raw data, taking all input and metadata into account. No smoothing filters were applied at any time during the analyses within the current study. This data was then synchronised based on the time stamps of the criterion measures and the start of the GPS data was set for the first acceleration where a velocity >2 $m \cdot s^{-1}$ was reached after a 10 s period of static behaviour prior to the first section of the protocol (Hoppe et al., 2018).

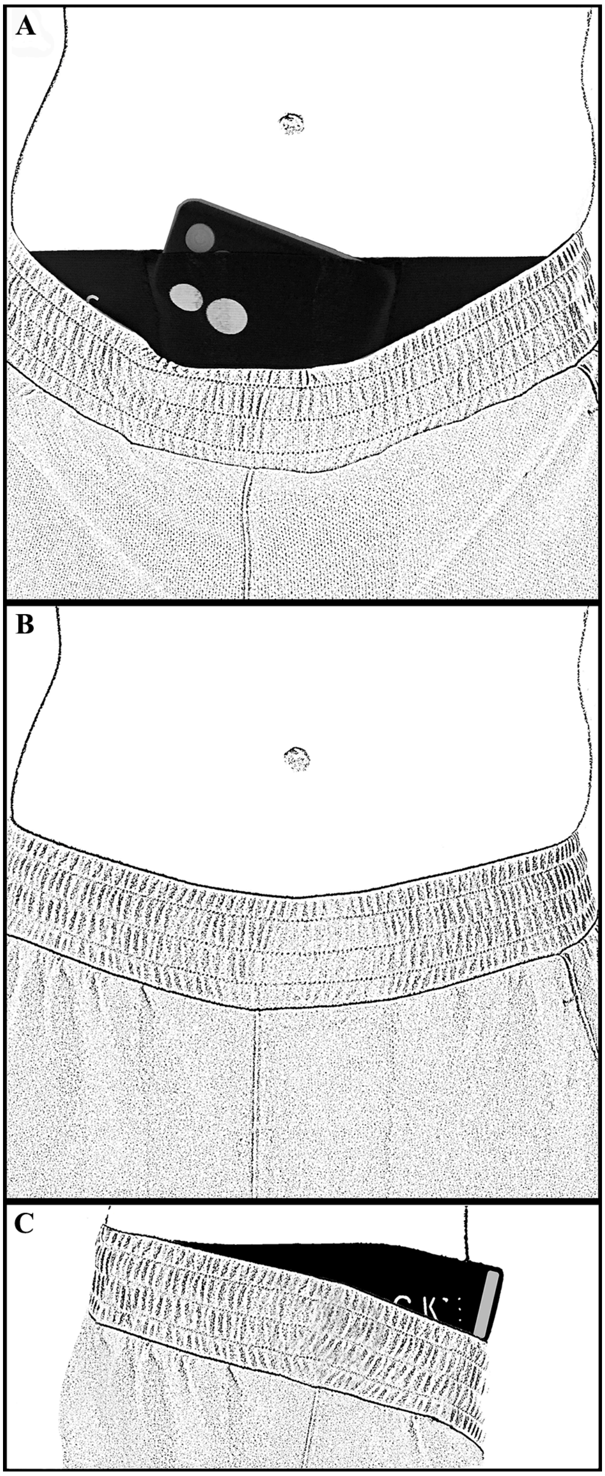

Figure 17. *Abdominal positioning of the GPS device. The top image (A) shows the specifically designed belt wherein the GPS device is secured by sliding it in from the top. The middle image (B) shows the final wearing situation, where the belt and device are concealed and secured by the shorts of the player. The bottom image (C) shows the side view, where the device (depicted in grey) is tilted forward to improve satellite reception.*

Actual distance as well as average and peak velocity were included as criterion measures and recorded using a measuring tape, single-beam timing gates (TC PhotoGate, Brower Timing, Draper, USA), and a hand-held radar gun (ATS-II, Stalker Sport, Richardson, USA). The timing gates were placed along the course to measure average velocity over intervals ranging from 20 to 50 m (Earp and Newton, 2012; Haugen et al., 2014). Peak velocity was measured for six players during sections C and D (see Figure 16; (Beato et al., 2018).

Statistical Analysis

Outcomes are displayed, where appropriately, as mean ± SD and prior to analysis, all data was checked for normality using the Shapiro-Wilk test. CL were reported within square brackets. The standard error of the estimate (SEE) was calculated to determine the validity of the system for all different movements within the protocol (Petersen et al., 2009). The SEE is the standard deviation (reported along with 95% CL) of the %-difference between the GPS's time-motion data and criterion measures. The percentage difference was reported as the bias of the devices.

To determine the reliability of the GPS devices, both absolute errors (typical error; TE) and those expressed as a percentage (CV) were determined for distance and peak velocity (Jennings et al., 2010). The CV was rated qualitatively as *good* (<5%), *moderate* (5-10%), or *poor* (>10%) (Duthie et al., 2003; Scott et al., 2016). For the distance covered within the complete session, the true between-device SD was calculated using a linear mixed model. Within the model, trial was included as the fixed effect, whilst the device, device-by-trial interaction and the residual error were random effects.

Furthermore, as the timing gates only provide average velocity, the GPS data was averaged for the corresponding section of the course and separated into four different speed zones: walking (< 7.2 $km \cdot h^{-1}$), jogging (7.2 - 14.4 $km \cdot h^{-1}$), high-speed running (14.4 - 21.6 $km \cdot h^{-1}$), and very high-speed running (> 21.6 $km \cdot h^{-1}$; Carling et al., 2012; Dwyer and Gabbett, 2012). The same zones were also used to describe the intensity of the protocol, by separating the recorded GPS data. Both instances and distances per speed zone were based on a minimum duration of 0.6 s above the threshold speeds. Pearson correlations (r) were calculated to determine the validity of the speed values derived from the GPS and criterion measure, as well as the relationship between the error and average speed measures. The magnitude of correlation was assessed using the following thresholds: <0.1, *trivial*; 0.1 to 0.3, *small*; 0.3 to 0.5, *moderate*; 0.5 to 0.7, *large*; 0.7 to 0.9, *very large*; and 0.9 to 1.0, *almost perfect* (Hopkins et al., 2009). All statistical methods were conducted using the statistical software package SPSS (Version 24; SPSS Inc., Chicago, IL, USA).

4.2.2 Results

The average distribution within the four speed zones throughout the protocol is presented in Table 6.

Table 6. *Average distribution of distance and instances amongst four different speed zones within one session of the protocol.*

	Walking	Jogging	High-Speed Running	Very High-Speed Running
Distance (m)	144.0	240.1	87.5	28.4
Instances	27	30	7	2

Note: Speed zones are separated into walking (<7.2 km·h^{-1}), jogging (7.2- 14.4 km·h^{-1}), high-speed running (14.4-21.6 km·h^{-1}), and very high-speed running (>21.6 km·h^{-1}).

Validity

The precision of the GPS system during all movements of the validation protocol is presented in Table 7.

Table 7. *Validity and reliability of the GPS-system for each movement and the complete session including stationary phases.*

	Distance Bias (%)	Distance SEE (% [CL])	Within-device distance TE (m [CL])	Within-device distance CV (% [CL])
Sideways	2.4	4.9 [3.8; 6.9]	3.2 [2.0; 7.1]	7.3 [4.7; 16.2]
Diagonal	-1.0	5.6 [4.2; 8.6]	3.6 [2.2; 8.7]	8.8 [5.5; 21.6]
Acceleration	-4.0	5.4 [4.3; 7.4]	2.8 [1.9; 5.3]	8.6 [5.8; 16.6]
Deceleration	0.0	4.3 [3.4; 6.0]	1.7 [1.2; 3.3]	4.9 [3.3; 9.4]
Backwards	-8.0	6.0 [4.6; 8.6]	3.4 [2.2; 7.6]	10.9 [7.0; 24.1]
Shuttle	2.5	3.4 [2.7; 4.6]	2.7 [1.9; 4.7]	4.6 [3.2; 8.1]
Skipping	-3.1	8.6 [6.6; 12.1]	5.4 [3.6; 11.0]	17.4 [11.5; 35.4]
Session	0.8	3.1 [2.2; 5.8]	6.7 [3.8; 25.1]	2.0 [1.2; 7.6]

Note: SEE = standard error of the estimate; CL = 95% confidence limits; TE = typical error; CV = coefficient of variation.

The SEE of the average velocity during the movements was found to be 5.4% [5.0; 5.9], with the average velocity measured by the timing gates and GPS indicating a significant and almost perfect correlation ($r = 0.98$ [0.97; 0.98], $p < 0.01$). The SEE for the speed zones was found to be 12.3% [10.5; 14.7] for walking, 9.3% [8.4; 10.4] for jogging, 6.0% [5.1; 7.3] for high-speed running, and 5.0% [3.4; 9.6] for very high-speed running. Here, a significant and almost perfect correlation between SEE and the different ranges of velocity was found, describing a greater accuracy at higher speeds ($r = 0.96$ [0.88; 0.99]; $p = 0.04$). No significant correlation was found between the average velocity of the seven sections and the absolute error ($r = -0.29$ [-0.86; 0.59], $p = 0.26$).

The SEE of the peak speed was found to be 3.4% [2.6; 4.8], with no significant difference in the errors during movement C (maximal acceleration) and D (maximal deceleration; $p = 0.39$). Finally, a significant and very large correlation was found between peak speed measured by GPS and radar ($r = 0.79$ [0.57; 0.91], $p < 0.01$).

The system was found to both over- and underestimate criterion distance for different movements within the protocol, resulting in a small overestimation bias for the complete session (0.8%). A systematic underestimation of criterion velocity was recorded, with an underestimating bias of 7.2%.

Reliability

The highest variation, as can be seen in Table 7, was found during skipping movements involving 180-degree turns while moving sideways. Collectively, the total distance of the session indicated a good reliability (<5%), the reliability for five of the drills was moderate (5-10% CV), whilst backward and skipping movements indicated poor reliability (>10% CV). Furthermore, a TE of 0.25 $m \cdot s^{-1}$ [0.17; 0.46] was found for the test-retest error within peak speed, leading to a CV of 4.7% [3.2; 8.5] of the error between the trials. A Bland-Altman analysis also revealed agreement within the intra-unit differences (see Figure 18).

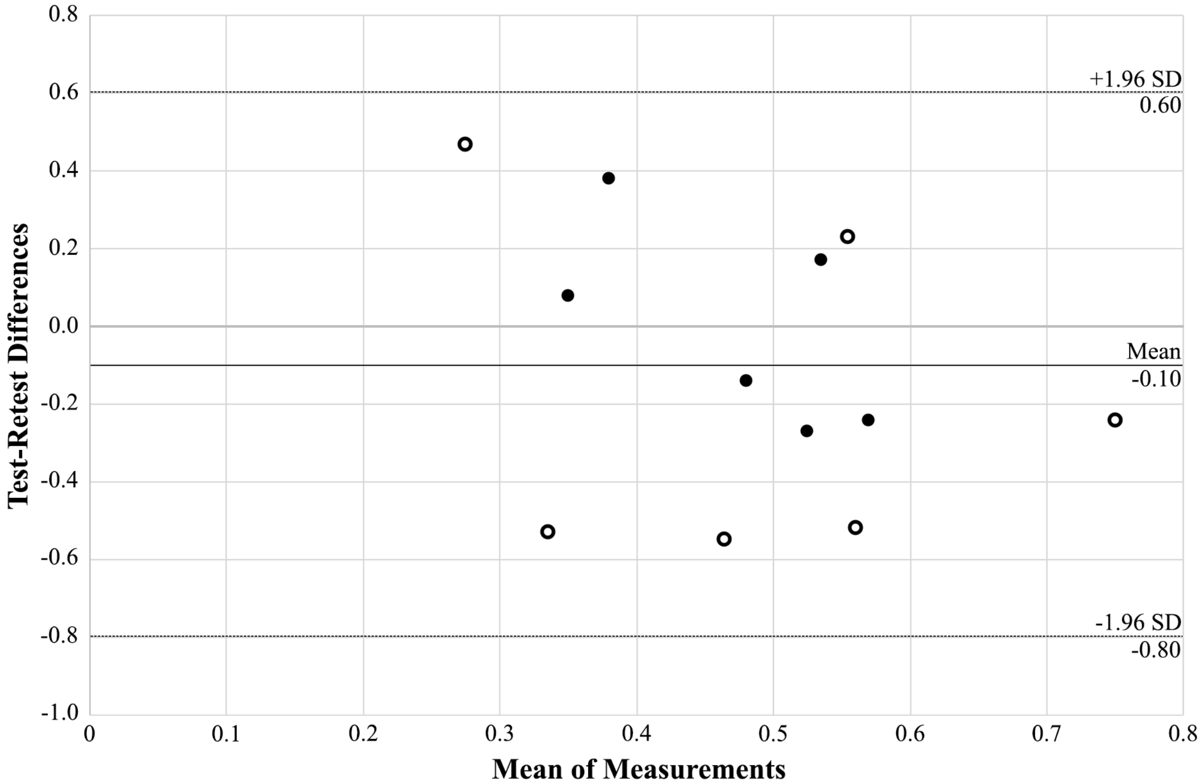

Figure 18. *Bland-Altman plot for the test-retest error in peak velocity (in m·s-1). Black dots represent acceleration runs and white dots deceleration runs. SD = standard deviation.*

An observed 78.8% of the variance in total distance covered was due to the individual device. Since each player was assigned a specific device, the variance describes a players' variation in the execution of the trial. A further 20.8% of variance was explained by the interaction between the device and trial. Finally, merely 0.4% was explained by random errors. The true between-device SD, the intercept of the model, was found to be 2.9% for the complete session, which translates to 14.5 m over the 500 m course.

4.2.3 Discussion

The present study aimed to determine the accuracy of a newly designed low-cost GPS system. Time-motion data was gathered during a continuous protocol involving different movements specific to match-play in football and compared with two criterion measures (distance and velocity). The repeated execution of the protocol allowed for the calculation of the system's reliability. Overall, good accuracy was found for the distance covered during the complete protocol, with a SEE of 3.1% [2.2; 5.8] for validity and a CV of 2.0% [1.2; 7.6] for intra-unit reliability. For peak velocity, despite a systematic underestimation, similar results were found, where a SEE of 3.4% [2.6; 4.8] and a CV of 4.7% [3.2; 8.5] indicate appropriate validity and reliability. Errors and variance increased when movements deviated from a straight line, however remained within previously reported ranges of acceptability (<10%; (Scott et al., 2016). Furthermore, variations in change of direction ability may lead to differences between individuals executing the identical course, leading to the largest portion of variance. However, the overall true between-device SD was found acceptable (2.9%).

Interestingly, where previous studies have often found GPS systems to become less accurate with increasing velocities, the results of the current study indicated a small correlation between average velocity and the associated error (Coutts and Duffield, 2010; Jennings et al., 2010; Johnston et al., 2014). Relative to the velocity itself, the error was found to decrease with increasing average speeds over sections of the course. This effect was not due to changes of direction, which would decrease the average velocity, since no significant correlation between movement velocity and error was found. Additionally, the lowest accuracy was found for moving backwards in a straight line, whilst the greatest accuracy was found for shuttle running, which included four 180 degree turns. As such, high-speed movements, regardless of the direction of movement, may be confidently measured with the current GPS system. The significance of this finding lies with the notion that high-speed activities are considered highly important when analysing running behaviour in football (Carling et al., 2012; Faude et al., 2012).

Whilst the GPS devices used in the previously mentioned studies are designed to be worn in between the scapulae for improved satellite reception, the devices used in the present study are worn on the lower abdomen (see Figure 17). A placement close to the centre of mass (COM) has been proposed as more sensitive to changes in human gait in comparison to a "standard" placement on the upper back (Barrett et al., 2016). This may be explained by biomechanics, which defines positional tracking as the displacement of an individual's COM (Floor-Westerdijk et al., 2012). As such, the differences between the displacement and rotation of the COM and that of the shoulders whilst running are vastly different (Seay et al., 2011). With increasing velocities, arm swing becomes more pronounced and the greater displacement of the shoulders could increase noise for devices positioned in between the shoulder blades (Barrett et al., 2016). The same reasoning may explain the relatively limited accuracy of the current system when moving at lower velocities, sideways or backwards. When standing still, moving slowly, or not in a forward direction, movements of the abdomen and hips, unrelated to forward locomotion, might impact the accelerometer data. As introduced, this input plays a vital role in the final calculations of the time-motion data. Therefore, the positional data, otherwise relying on a relatively low sampling frequency of 5 Hz, may be greater affected. With increasing velocities, the movements around the COM will be predominately due to the locomotion itself, thereby possibly lowering the noise within the measurements and improving data accuracy. As such, this reduces the requirements for the hardware. For example, the current system features 5Hz GPS units in comparison with 15 Hz units in advanced systems used in elite environments. Consequently, the costs of the system can be minimised, increasing its availability across an array of competitive standards.

To further identify the effect of wearing positions, being in between the shoulder blades or on the lower abdomen, devices should be tested more intensively. However, this proves difficult with commercial GPS systems, since the devices are designed to be worn due to the manufacturer's specifications. The input from the GPS-chip and accelerometer are converged in such a way, that the final time-motion data is most accurate when the tracker is worn in its intended location. Therefore, wearing a second device in an unintended position and comparing the results would be unrelated to the accuracy and specificity of the system. Comparisons of performance data collected by systems worn in different positions should also be avoided until further studies have been performed regarding the effect of device placement.

Because even when wearing two devices simultaneously close to their intended location, to calculate inter-unit variability (Rampinini et al., 2015), difficulties may arise. It has been found for different devices, that a certain distance should be present in between two devices, in order to exclude noise generated by the devices themselves (Hoppe et al., 2018). For the current system, it was deemed impossible to wear two devices on the designed location without affecting satellite reception, data or natural movements. It is because of these considerations, that the current study did not compare simultaneously worn units. However, the repeated use of the criterion measures provides an appropriate measure of intra-unit reliability (Beato et al., 2016). In order to allow for this intensified use of the criterion measures, the current study did not replicate previously performed protocols. Studies validating GPS systems for use in football have often performed a team sport running circuit (Bishop et al., 2001; Jennings et al., 2010). This protocol, however, only measures velocity over a short distance and thus, provides limited data on the variability of velocity.

The criterion measures for velocity should, however, be discussed, as both single-beam timing systems and hand-held radar were used in the present study to measure average and peak velocity, respectively. For such timing systems, larger errors have been found for small inter-gate distances (Earp and Newton, 2012). Therefore, the gates were placed at least 20 m apart and hand-held radar was used to measure peak velocity whilst accelerating and decelerating (Haugen and Buchheit, 2016). This meant different references were used, both with their specific errors of measurement. A possible solution would be the use of a high-resolution multi-camera motion analysis system, capable of accurately measuring instant velocity, regardless of the running direction (Duffield et al., 2010). Moreover, the use of such a reference system could provide the validation of more complex motions, like jumps or accelerations and decelerations. This would be advantageous as such short and explosive actions are deemed highly influential on player load (Harper and Kiely, 2018). Accurately providing such information would further increase the impact of any tracking system. However, although desirable, this validation technique is costly and not easily accessible. Nonetheless, it could be attempted by future studies to use such a high-speed motion analysis video system to preferably validate a variety of tracking systems (Hoppe et al., 2018; Linke et al., 2018). Moreover, this may also lead to direct comparisons of the effect of wearing position, like the current abdominal solution and that of previously validated GPS systems, worn between the scapulae.

Nevertheless, comprehensive data was collected through the protocol performed within the present study. The largest errors were found for sideways skipping and backwards jogging, which were found to be the least common types of locomotion during football matches (4.4% and 6.5% of time in motion, respectively; (Bloomfield et al., 2007). Although better accuracy for all types of movements would be optimal, these errors do not seem to diminish the acceptable results for total distance and velocity.

Practical Applications

Prior to the implementation of a tracking system into practice, the characteristics of the data they collect should be understood, regardless of the population of players (Buchheit et al., 2014). The GPS system in the current study was found to provide accurate and valid movement data. These findings are of particular importance due to the devices being designed to be more accessible and available for sub-elite teams; extending its applicability across a broader spectrum of coaches and practitioners. Potentially improving the scientific standard across all levels of the sport, for both performance as well as medical applications, allowing for better monitoring of athletes.

The accuracy of the current system, with a true-device SD of 2.9%, was deemed acceptable to indicate practically meaningful changes within the running load of players. For describing high-speed actions, considered highly important in football, the current system also shows to be a suitable tool, as acceptable accuracy was found for peak speed during sprinting and for average velocity within higher speed zones. Although no device-specific bias was found, the assignment of a specific device per player is advised, since no simultaneous tests were performed in the current study. Finally, practitioners should refrain from comparing training or match data from systems with different device placements, until further studies have been performed.

4.2.4 Conclusion

Taken together, the newly-designed GPS system used in the present study was shown to be sufficiently valid and reliable, and can thus be used with confidence for measuring running load in football. For the distance covered during the complete session, good validity, as well as intra-unit reliability was found. Peak velocity was found to be valid and reliable, since the systematic underestimation was determined unsubstantial. When changes in direction and style of locomotion were introduced, the accuracy decreased, however remained within previously published ranges of acceptability (<10%). Since the system relies on more affordable hardware components, it offers a lower financial burden which makes it available for sub-elite teams. This allows for a higher practical as well as scientific standard across multiple levels. Coaches and sport scientists may improve their monitoring and analyses, ultimately aiding the on-field performance. From a scientific standpoint, low-cost GPS devices like the currently validated systems may increase the numbers of studies performed, with greater sample sizes leading to a greater pool of data; providing novel insights into various aspects of football which elite teams may not be inclined to provide.

Chapter 5

Identifying physical characteristics during goal scoring opportunities

5.1 Optimising preparation and selection

With the validity of the tracking solution confirmed, the path is clear to look further into the behaviour of players during promising attacking sequences. For this purpose, sub-elite teams, willing to share detailed tactical as well as physical match data, may be recruited. That means, physical parameters may be compared during specific tactical styles of play. If certain characteristics (like player activity or the intensity of movements) are more apparent during typical or even successful attacks, player preparation and selection may be supported as a consequence (Sarmento et al., 2016). These profiles could be optimised for players from one's own or an opposing team, as information regarding (tactical) playing characteristics may be retrieved for any team or player as long as time-motion data is available.

Effectiveness seems to play a deciding role again. So far, it has been established which phases and types of attack are known to disturb inter-team balance and improve attacking effectiveness. By taking one more step back, player involvement and behaviour during these phases may shed a deciding light on how to play. As introduced before, individual players merely form the basis for a team and do not decide matches by themselves, but individual behaviour is easiest to alter and improve (Liu et al., 2016). By knowing what physical player characteristics correspond with successful outcomes, individual player behaviour may be optimised, making the team more effective (Sarmento et al., 2016).

And as found earlier in the current research programme, spaces may be deemed crucial for a player to become threatening. Spaces need to be sought, found and/or created. If everyone would stand still, generally nothing would happen. Consequently, players need to move. How and where, seems to depend on the context (Aquino et al., 2017). From situational aspects of context, like the venue or the quality of opposition (Castellano et al., 2011a), to tactical aspects, like opponent formation or playing style (Bradley et al., 2011; Carling, 2011); all were found to lead to differences in running output. The inter-team balance introduced in the previous chapters can also be considered a contextual factor affecting playing effectiveness (Goes et al., 2020). In general, the presence and positioning of opponents and the location of the ball itself seem to impact the characteristics and outcome of the attack. As such, it may be questioned how attacking players can behave to create such situations or make optimal use of the spaces provided.

Whilst the previously introduced results show how the overall playing effectiveness (creating and converting more GSOs) and physical characteristics (distance covered or top speed reached) depend on context, the question remains whether it is possible to combine these aspects (Bradley and Ade, 2018). In order to disturb the balance with(in) the opponent's organisation, attackers should constantly alter their running behaviour (for example speed and direction) to become unpredictable for defenders. Faude and colleagues have shown that straight sprints most often precede a goal (Faude et al., 2012). However, as this merely describes the final moment during the attack, having all attackers simply sprint towards the goal after receiving or in anticipation of a pass, may become predictable, diminish spaces and not lead to many (more) goals. As previously described, context seems to dictate the effectiveness. Consequently, it would be of interest to know what influences this running behaviour. Exploring whether previous physical output or contextual factors are related to such acute running strategies and allow for more (effective) GSOs, may potentially strengthen future analyses. In other words, practitioners may be informed on their team's or the opponent's effectiveness in creating, converting or preventing match-deciding sequences like GSOs.

Therefore, the following study aimed to investigate the running behaviour leading up to GSOs. First, it was determined whether physical output was related to the success of the attempt. This involved analyses from an offensive (creating the GSO) and defensive (preventing the GSO) standpoint. Subsequently, tactical and situational factors were studied to potentially explain the observed differences in running behaviour.

5.2 Exploring Factors Related to Goal Scoring Opportunities in Professional Football

The following subchapters appear as published in "Science and Medicine in Football" on the 11th of May 2021. The full publication can be found as an appendix at the end of the thesis.

5.2.1 Methods

Design

The observational design of the current study aimed to investigate the running behaviour of outfield players leading up to GSOs during football matches. Tracking data of a professional team was collected over one complete season, using GPS monitoring. The physical output prior to scoring attempts was analysed from an offensive and defensive perspective, to explore its relation with outcome and contextual factors.

Subjects

Match data was collected from all outfield players of a German professional male football team during the 2016/2017 Regionalliga season (4th national league; age: 26.3±4.3 yrs.; height: 180.7±5.9 cm; weight: 77.8±5.1 kg). Every player provided consent to the anonymous use of their match data. The study was ethically approved by the local Human Research Ethics Committee and performed according to the Declaration of Helsinki.

Data Collection

During the season, all outfield players wore an individually assigned GPS tracker during 33 league matches (TT01, Tracktics GmbH, Hofheim, Germany; firmware version 1.7). The system was tested prior to the current investigation (Schulze et al., 2021). With an SEE, describing validity, of 3.1% and 3.4% for distance and velocity and CVs, indicating the reliability of the system, of 2.0% and 4.7% for distance and velocity, the system has been previously deemed valid and reliable for tracking running behaviour in football (Schulze et al., 2021). The quality of the GPS signal during the matches was deemed appropriate; on average 11.4 satellites were connected with an HDOP of 0.89, describing an appropriate spread of the satellites in the sky (Scott et al., 2016).

Tactical match footage, showing all players at all time, was provided by the participating team for every match. In the end, 427 individual match observations were collected from 23 different players, involving starting players and substitutes. The GSOs created and conceded by the participating team were selected based on two criteria: 1) the attack had to originate from open play, which means the attacking team could not have had a set piece (goal kick, throw in, free kick or corner kick) in the 20s prior to the shot (Gonzalez-Rodenas et al., 2020; Kempe et al., 2014); and 2) the attacking team should have had at least 5 s of uninterrupted possession, in order to determine the type of attack (Tenga et al., 2010b). After the application of these criteria, 220 GSOs (145 created and 75 conceded by the participating team) were selected for further analysis.

Parameters

In order to describe the running behaviour of the player taking the shot (described as the attacker), or the defender trying to prevent the shot (described as the final defender), three parameters were collected: the maximal running velocity reached during the attacking sequence leading to the GSO, as well as the total and high-intensity distance (HID) covered in the 1 and 5 minutes prior to the attempt. The short time frame of 1 minute was selected to potentially involve high-intensity actions, as close to the attempt as possible (Scott et al., 2016). The larger window of 5 minutes was selected as it most certainly contains a change in ball possession, however was still found to relate to the physical output at the end of the time frame (Bradley et al., 2013b; Fransson et al., 2016). On the team level, the maximal running velocity described the highest velocity recorded within the team (potentially, however not necessarily, the player taking the shot or final defender). The total and high-intensity distance covered in the 1 and 5 minutes prior to the GSO was the calculated as the average of all outfield players. The total and high-intensity match distance was computed by averaging the distances of those players completing the entire match. For both the individual and team parameters, two high-intensity thresholds were used. First, an arbitrary speed zone for HID was used (14.4 $km \cdot h^{-1}$; (Carling et al., 2012). Second, an individualised threshold was applied, since the data was collected from a single team, thereby allowing for a more sensitive approach (Abt and Lovell, 2009). This threshold was based on the lactate threshold speed, which averaged at 14.5 $km \cdot h^{-1}$ for all individual players (Hunter et al., 2015). These values, describing aerobic fitness, were calculated after performing incremental step tests during pre-season and in the winter break. The average of both tests was used for each player.

The tactical side of the contextual factors were described by several parameters. First, the type of attack was identified. In line with previous research, attacks were categorised as 1) a counter attack, when the defensive team was unorganised and passes were mainly directed forwards; 2) direct, when the defensive team was organised and passes were mainly directed forwards; or 3) elaborate, when the defensive team was organised and passes were directed forwards, sideways and backwards (Gonzalez-Rodenas et al., 2015; Lago-Ballesteros et al., 2012; Sarmento et al., 2018). Second, the number of defenders behind the ball was determined for several moments during the attack: when possession was won, at 10 as well as 5 seconds before the GSO, and at the moment of the attempt (Schulze et al., 2019). Third, the zone of ball possession at the same moments during the attack was recorded. For this parameter, twelve different zones on the field were used, as previously suggested by Sarmento and colleagues (see Figure 19; (Sarmento et al., 2018). The outcome of an attack was categorised as "goal", "save" (where the goalkeeper or final defender between the ball and the goal cleared the attempt), and finally "off target" (when the attempt went wide of the target or hit the post or crossbar). Finally, the playing position of the player taking the shot was recorded to individualise context. Due to the applied nature of the study, players were separated into three subgroups: defenders, midfielders and attackers.

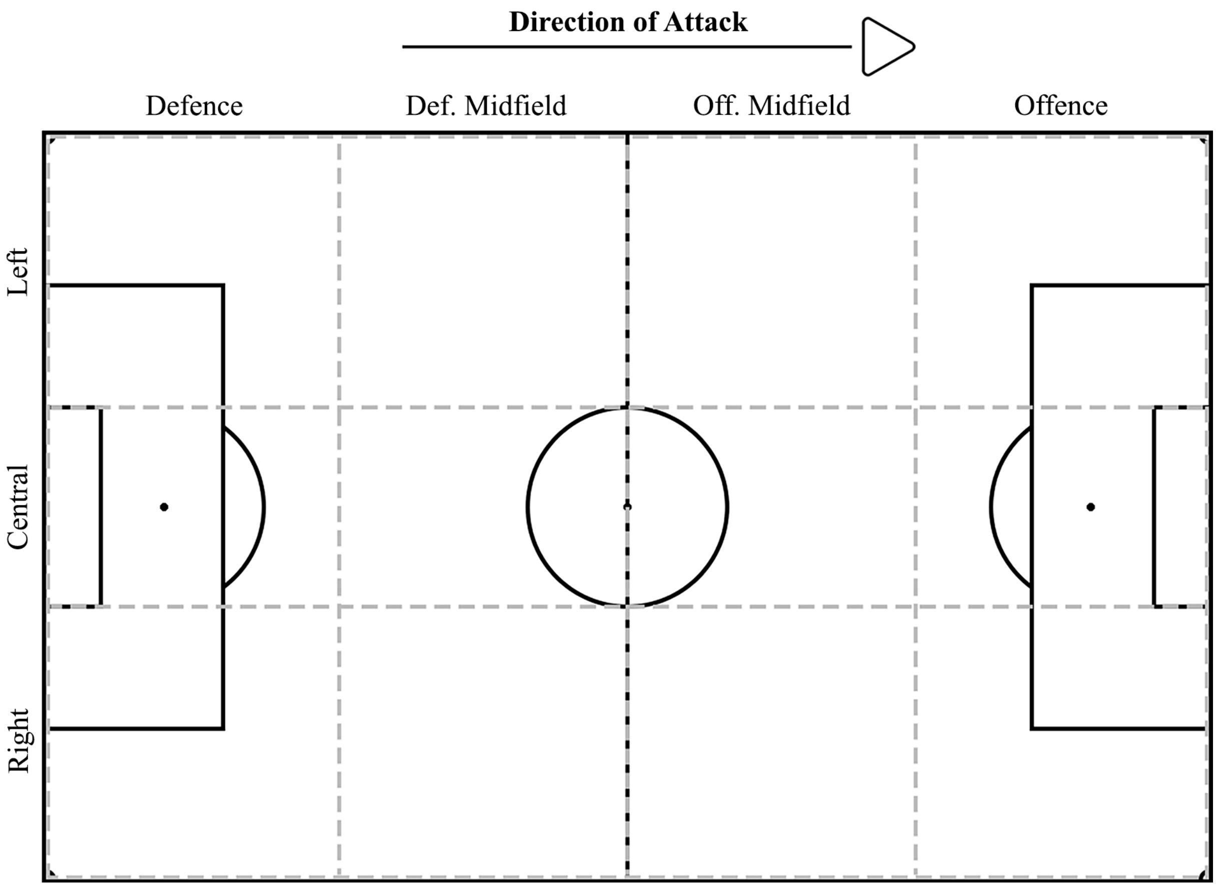

Figure 19. *Distribution of the pitch, used to describe the zone of ball possession at the various moments during an attacking sequence.*

The situational aspects of match context were the venue (home or away), the time point the GSO took place during the match, and the opponent's level (long-term quality) as well as their form (short-term quality). For team level, the ranking during the specific half of the season and the final standing in the league table were used as separate measures (Brito Souza et al., 2019). For team form, the percentage of points gathered during the five league matches prior to the current match was calculated.

Statistical Analysis

Values were displayed as Mean ± SD or with 95% CL when deemed appropriate. Factor analyses, using a PCA, were performed to discover which combinations of physical or contextual parameters explained most variance within the data (Fernandez-Navarro et al., 2016). Several criteria had to be met: first, Bartlett's test of sphericity was used to indicate sufficient inter-variable correlation; second, the minimal eigenvalue to separate factors was set at 1; and third, factor loadings of 0.7 or higher were required for further analysis (Fernandez-Navarro et al., 2016). The collections of factors determined through the PCA were tested through multiple regression analyses. Linear regressions were also calculated for each separate factor. The magnitude of correlation (r) was assessed using the following thresholds: <0.1, trivial; 0.1 to 0.3, small; 0.3 to 0.5, moderate; 0.5 to 0.7, large; 0.7 to 0.9, very large; and 0.9 to 1.0, almost perfect (Hopkins et al., 2009). SPSS Statistics was used for all statistical tests (version 24; IBM, Chicago, IL, USA).

5.2.2 Results

The characteristics of the analysed GSOs can be seen in Table 8. Counter attacks recorded most goals scored from the least attempts, with 24.6% of all counter attacks leading to goals, compared with 12.4% and 11.4% for elaborate and direct attacks, respectively. Furthermore, counter attacks were characterised by fewest defenders behind the ball during the final 10 s of the attack (3.0±1.4, compared with 4.6±1.6 and 5.5±2.8 during direct and elaborate attacks, respectively). Consequently, the outcome of the GSO was found to correlate significantly with the number of defenders behind the ball at the time of the shot ($r=0.27$ [0.11, 0.42]; small; $p=0.03$). When taking playing position into consideration, although most shots were taken by midfielders, attackers were found to be more effective, independent of attacking style (25.5% compared with 15.3% and 11.1% for midfielders and defenders, respectively).

Table 8. *Description of the included created (offensive) and conceded (defensive) goal-scoring opportunities, separated for venue and attacking style.*

		N	Goal	Save	On T	Post	Wide	Off T
Offensive	**Total**	145	27	65	92	5	48	53
	Home	77	17	29	46	5	26	31
	Away	68	10	36	46	0	22	22
	Elaborate	62	8	28	36	2	24	26
	Direct	43	7	22	29	2	12	14
	Counter	40	12	15	27	1	12	13
Defensive	**Total**	75	7	34	41	2	32	34
	Home	34	3	17	20	1	13	14
	Away	41	4	17	21	1	19	20
	Elaborate	27	3	11	14	1	12	13
	Direct	27	1	14	15	0	12	12
	Counter	21	3	9	12	1	8	9

Note: 'On T' describes the number of attempts ending on target, the summation of goals and saves. 'Off T' describes the number of attempts ending off target, the summation of attempts hitting the post (or crossbar) and those wide of the goal.

Attacking Effectiveness

The PCA analyses revealed that the attacker's physical output in the minute prior to a goal explained 44.5% of the variance within the physical parameters, whereas the running behaviour in the preceding 5 min explained 34.4%. For a non-successful attempt, 38.2% of the variance was explained by the 5 min output, compared with 34.7% by the 1 min output. The combined 1 min factors showed a significant correlation with outcome (r=0.26 [0.10, 0.41]; small; p=0.04). In contrast, no significant correlation was found for the 5 min physical output.

Table 9. *Description of physical parameters for the attacker (the player taking the shot), the offensive team, the final defender (trying to prevent the shot) and the defensive team.*

		Goal	No Goal	Correlation
Attacker	**1 min distance**	115.9 (29.0)	104.0 (31.7)	**0.27 (p=0.03)**
	1 min HID	24.2 (28.9)	22.5 (20.3)	
	Max velocity	21.7 (4.4)	20.8 (4.2)	0.09 (p=0.29)
	5 min distance	95.9 (36.7)	103.0 (27.5)	0.09 (p=0.26)
	5 min HID	19.2 (14.5)	20.0 (11.1)	0.18 (p=0.10)
Offensive team	**1 min distance**	108.5 (26.1)	105.2 (28.9)	0.05 (p=0.59)
	1 min HID	19.6 (11.3)	17.4 (10.4)	0.08 (p=0.31)
	Max velocity	25.3 (2.5)	25.4 (2.6)	0.13 (p=0.88)
	5 min distance	96.3 (26.3)	100.8 (24.6)	0.12 (p=0.15)
	5 min HID	15.7 (7.1)	16.0 (5.4)	0.03 (p=0.69)
	Match distance	104.2 (5.0)	106.0 (4.5)	0.15 (p=0.07)
	Match HID	15.7 (1.8)	16.9 (2.7)	**0.20 (p=0.02)**
Final defender	**1 min distance**	143.9 (49.1)	105.8 (29.9)	**0.51 (p<0.01)**
	1 min HID	42.0 (54.3)	15.9 (18.2)	
	Max velocity	16.5 (4.3)	19.2 (4.0)	0.19 (p=0.09)
	5 min distance	118.7 (44.8)	100.7 (17.6)	**0.42 (p=0.01)**
	5 min HID	31.8 (44.5)	15.6 (8.3)	
Defensive team	**1 min distance**	93.1 (22.9)	84.1 (20.4)	0.13 (p=0.27)
	1 min HID	16.9 (11.6)	13.9 (9.0)	**0.24 (p=0.04)**
	Max velocity	23.7 (2.0)	24.7 (2.6)	0.12 (p=0.32)
	5 min distance	88.9 (14.5)	81.7 (12.2)	**0.49 (p<0.01)**
	5 min HID	18.4 (5.7)	14.2 (3.7)	
	Match distance	83.9 (6.4)	81.2 (8.7)	**0.29 (p=0.04)**
	Match HID	17.3 (1.5)	14.5 (2.2)	

Note: The data is presented as mean (standard deviation) in $m \cdot min^{-1}$ for distances and $km \cdot h^{-1}$ for velocity and separated for those attempts that led to a goal and those that did not. The correlation coefficients are presented with the level of significance in brackets. Significant correlations ($p < 0.05$) are marked in bold and vertical borders highlight the data it applies to (single or multiple regression). HID: high-intensity distance based on individualised thresholds.

On a team level, no differences in factors between the PCA analyses for successful and non-successful attempts were found for the offensive team. However, a significant correlation was observed between match HID and outcome ($r=0.21$ [0.05, 0.36]; small; $p=0.02$, see Table 9).

The PCA analyses of the final defender's physical output revealed no specific factor combinations for attacks that led to a conceded goal. However, for attacks that were defended successfully, 1 min physical output explained 38.0% of the variance within factors and 5 min running behaviour 32.6%. The multiple regression analyses of these components showed significant correlations between outcome and the running behaviour in the minute leading up to the attempt and in the 5-min period prior to the attempt ($r=0.51$ [0.38, 0.62]; large; $p<0.01$ and $r=0.42$ [0.28, 0.55]; moderate; $p=0.01$, respectively). All physical parameters were found higher when the attempt led to a goal in comparison with a non-successful attempt (see Table 9).

For the defensive team, the PCA analysis revealed that the physical output of the team prior to an attempt explained 46.1% of the variance and the running behaviour during the match 26.8%. Multiple regression analyses then showed significant correlations between outcome and the 5 min output, as well as the physical output during the match ($r=0.49$ [0.35, 0.61]; moderate; $p<0.01$ and $r=0.29$ [0.13, 0.44]; small; $p=0.04$, respectively). For the team's physical output in the minute leading up to the conceded attempt, a significant correlation between 1 min HID and outcome was found ($r=0.24$ [0.07, 0.39]; small; $p=0.04$, see Table 9).

Contextual Factors

First, tactical parameters were added to the analyses between outcome and the preceding physical output. Merely for elaborate attacks, a difference in the PCA analysis was found, with 46.0% of the variance within factors explained by the running behaviour in the 5 min prior to the attempt, in comparison with 30.1% for the 1 min output. The multiple regression analyses revealed a significant correlation between outcome and the overall physical output of the attacker, described by total distance and HID, in the 5 min prior to an attempt following an elaborate attack ($r=0.35$ [0.21, 0.50]; moderate; $p=0.02$). For the output in the minute leading up to the attempt, significant correlations were observed between outcome and the 1 min total distance covered following an elaborate attack by the attacker and offensive team ($r=0.31$ [0.15, 0.46]; moderate; $p=0.02$ and $r=0.28$ [0.11, 0.43]; small; $p=0.03$, respectively). For the other tactical parameters, no significant correlations with outcome were found.

The comparison of the physical characteristics between different tactical contexts revealed several differences. First, a significant correlation between attacking style and the maximal speed reached leading up to the GSO was found for the attacker (counter: 22.6±4.2, direct: 21.1±3.7, elaborate 19.7±4.3 $km \cdot h^{-1}$; $r=0.28$ [0.12, 0.42]; small; $p<0.01$) and the offensive team (counter: 26.2±2.8, direct: 25.4±2.6, elaborate 24.8±2.3 $km \cdot h^{-1}$; $r=0.22$ [0.06, 0.37]; small; $p<0.01$). Also, the HID covered by the attacker in the 5-min period prior to the GSO was found to correlate with attacking style (counter: 15.9±8.9, direct: 20.9±11.1, elaborate: 21.6±13.3 $m \cdot min^{-1}$; $r=0.20$ [0.04, 0.35]; small; $p=0.02$). These differences in HID were based on individualised thresholds, with a non-significant correlation found using arbitrary thresholds ($r=0.15$ [-0.02, 0.30]; $p=0.07$). The inclusion of the playing position (of the player taking the shot) revealed a significant correlation with the distance covered in the minute leading up to the attempt, independent of outcome (defender: 124.7±30.2, midfielder: 115.8±32.8, attacker: 101.0±28.8 m; $r=0.24$ [0.10, 0.39]; small; $p<0.01$). No significant correlations were found between attacking styles and defensive running behaviour. Furthermore, physical parameters of the attacker or final defender were not found to correlate with the zones of ball possession before the attempt. However, the fewer opponents behind the ball at 10 seconds before the GSO, the higher speeds were reached within the offensive team (r=-0.22 [-0.37, -0.06]; small; p=0.01).

The PCA analysis of the situational context revealed that opponent quality and form explained 37.1% of the variance within all factors. The regression analyses of these parameters showed a significant correlation between the final league standing of the opponent and the HID covered by the final defender and defensive team in the 5 min prior to conceding a GSO (r=-0.24 [-0.43, -0.04]; small; p=0.02 and r=-0.41 [-0.59, -0.20]; moderate; p<0.01, respectively). No significant correlations were found between the physical output leading up to created or conceded GSOs and venue or time played in the match.

5.2.3 Discussion

Tracking data, as well as tactical and situational context were collected over one season to explore whether running behaviour was related to the effectiveness of GSOs in football. Contextual factors were subsequently studied to potentially explain these differences in physical output leading to created and conceded GSOs. Several physical parameters were found to relate to the outcome of the attack. It was found that the attacker's running behaviour directly leading up to the attempt (1 min prior), was of more importance than the output over a longer period (5 min prior). Furthermore, an increased total distance as well as HID covered in the minute before the attempt was found to positively relate to success. In contrast, an increased activity of the defender was found to be related to a higher likelihood of conceding a goal. On a team level, lower physical outputs during the match were related to more successful attacks, and increased outputs over a longer period of time were found to be related to the chances of conceding. The inclusion of tactical context revealed different success rates and physical characteristics of attacking styles, with more goals and higher offensive speeds recorded during counter attacks. However, when ball possession was closer to the opponent's goal, as during elaborate attacks, greater physical output of the attacker and offensive team was found to relate to increased success. Finally, the situational context was studied, which was only able to explain differences in running behaviour leading up to GSOs due to opposition quality. With stronger opponents, increased physical outputs during defensive sequences were found. Taken together, although the magnitude of most correlations were small or moderate, effective attempts were found to be related to an increase in distance covered during the attack and a lower match HID, potentially indicating the ability to create more space.

In line with previous studies, counter attacks were found to be the most effective style of play for scoring goals (Lago-Ballesteros et al., 2012; Sarmento et al., 2018). Although the fewest attacks were classified as a counter attack, they resulted in the greatest number of goals scored (see Table 8). This playing style was also characterised by fewer defenders in between the ball and the goal. These spaces, which attackers can utilise, have previously been described as indicators of an imbalanced defensive organisation (Tenga et al., 2010a). Another important aspect of team balance are the movements of both teams, as previously concluded by Moura and colleagues (2016) and more recently by Goes and colleagues (Goes et al., 2020; Moura et al., 2016). The current study found a significant correlation between attacking effectiveness and increasing distance covered by attackers (looking for space) and defenders (covering their opponents) in the minute prior to an attempt. As it becomes more difficult to maintain intra- and inter-team balance when players are moving quicker, these results seem to confirm the importance of this concept (Goes et al., 2020; Kempe et al., 2014). It does not appear that defenders simply increase their physical output when they realise that the opponent is about to create a threatening GSO. This is explained by the data, demonstrating that regardless of changes in ball possession, an increased physical output of defenders in the 5-min period prior to a GSO was related to the subsequent outcome.

During counter attacks, where open spaces were largest, both attackers and defenders have been found to cover as much ground as quickly as possible (Lago et al., 2010). This is partially confirmed by the present results, stating that both the player taking the final shot, as well as the overall team in attack, reached higher speeds during counter attacks. Interestingly, no correlations between physical output and attacking styles were found for defenders. This accentuates generally different positional requirements, also for given playing styles. Furthermore, the present study found a correlation between the covered HID, based on individualised thresholds, in the 5-min period prior to a GSO and attacking style, with the attacker covering less HID before a counter attack. This decrease in HID potentially allows for the increased offensive output and may even implicate that offensive teams choose when to place a counter attack, depending on the activity prior to retaining ball possession and the acute status of their physical resources. This decrease in HID was not found for the minute prior to the GSO. This may be explained by the increased output during the attack itself or that teams have to cover more distance in defence, what usually precedes a counter attack (Castellano et al., 2011b). Interestingly, the significant correlation between attacking style and covered HID was, as mentioned, merely present for the distances calculated through individualised thresholds. Although the average thresholds differ only marginally (14.4 vs 14.5 $km \cdot h^{-1}$ for the arbitrary and individualised thresholds, respectively), substantial effects on an individual level may become apparent, as the spread in the individual threshold increases sensitivity, leading to statistically significant changes in the results. This shows the added benefit of sensitising data describing intensity when working with a single team (Carling et al., 2016; Hunter et al., 2015).

With the current study confirming that counter attacks are the most effective style of play for scoring goals, it would be a logical assumption that the found increase in physical output prior to successful attempts is merely due to attacking style. Counter attacks were indeed found to start deeper in the own half, consequently requiring a higher physical output to reach the opponent's goal. However, the attacker's as well as the offensive team's physical output was also found to correlate with success during elaborate attacks, where the opponent is organised and found standing closer to their own goal. This indicates that the found increases in running behaviour prior to a successful attack do not merely relate to attacking style. This is also confirmed by the analyses of the playing position of the player taking the shot. A significant correlation was found for the total distance covered in the minute leading up to an attempt, with defenders covering more ground, as they usually start an attack further away from the opponent's goal. However, no significant correlations were found between playing position and physical output prior to successful attempts, indicating the increased running behaviour to be independent of player positioning.

Apart from the differences in running behaviour during specific attacks, it was also found that the overall output during sequences leading to GSOs did not relate to the time played during the match, from both an offensive as well as a defensive point of view. This is an interesting finding, considering that physical output has been previously found to decrease during a match (Bradley et al., 2009). This possibly indicates that players, regardless of playing position, are able to deliver the required physical output when it is most needed. As a result, this means they need to appropriately pace and recover during the match (Schimpchen et al., 2021). Three more findings seem to confirm the importance of endurance capacity and well-timed substitutions, in case a player or opponent is no longer able to reach the required output (Bradley et al., 2014). First, the outcome of conceded GSOs was negatively correlated with the preceding HID covered by the defender, describing higher values prior to conceded goals. Second, attacking outcome correlated with the HID covered during a match, indicating higher effectiveness for lower match outputs. Finally, an increased physical output in the minute leading up to the GSO was positively correlated with outcome. All of this seems to support the importance of a great physical capacity of the players and intelligent pacing, in order to be sufficiently recovered to increase one's activity when required (Bradley et al., 2013a; Link and de Lorenzo, 2016).

A further aspect where the physical output during attacking sequences showed contrasting patterns to that during the complete match, was that for match location. Castellano and colleagues (2011) described that teams playing at home covered more distance than teams playing away (Castellano et al., 2011b), whereas the current study found no significant correlations between the physical output during attacks leading to created or conceded GSOs and playing venue. This indicates that the physical output whilst creating or defending GSOs is independent of playing at home or away. As such, the previously found differences in match distance may relate to the increased activity during sequences that did not lead to GSOs or the number of attacks, as home teams were found to play more offensive (Lago, 2009).

Due to the applied nature of the current study, certain limitations were apparent. Since one team was supplied with tracking devices and no opponent data was externally available, the exact positioning of the opposing players was unknown. Such data would have been advantageous and this provides incentive for future studies to improve the understanding whether inter-player distances are affected by previous physical output and whether they play a role in the effectiveness of attacks (Goes et al., 2020; Moura et al., 2016). Furthermore, since the current data is collected from a single team, the results may not be fully transferrable to other teams or generalisable for a larger population. The results also mostly showed small correlations, potentially due to the relatively small sample size. Similarly, insufficient events were available to utilise individual player data as a potential factor. In the current study, merely shooting effectiveness and total distance covered, independent of outcome, presented differences between subgroups of players, based on general playing position. This leaves future studies to include a wider range of teams, include more advanced positional metrics as well as contextual factors and study individual player characteristics more intensively (Goes et al., 2020). However, the current study and results do show how practitioners may approach analysing their team's or an opponent's running behaviour leading up to GSOs. Where it is difficult to perform intervention studies directly impacting tactics in professional sports, the current study aimed to provide insights to directly impact training and match preparation. Additionally, the current findings accentuate that the meaningfulness of analyses could be enhanced when incorporating contextual data (Aquino et al., 2017). With increasingly more information on the effect of context gathered, it may eventually become possible to perform highly specific intervention studies relating to match analysis in (sub) elite football. Such studies, altering behaviour during isolated events, hold more scientific as well as practical power, making them extremely valuable to the field.

Practical Applications

By finding that effective attacks are related to an increased distance covered and fewer defenders behind the ball, the current study seems to highlight the importance of finding and utilising space and the capacity to increase one's physical output when required. As attacking effectiveness was also found to relate to less HID covered during the match, the importance of a great physical capacity is indicated. In general, attackers need to be capable of increasing their physical output to disturb the balance within the opponent's organisation and find space to take a shot. Similarly, defenders need to be capable to cover more ground to remain balanced with their teammates and close down their opponents. A team's tactical as well as individual pacing strategies should be thoroughly prepared and trained. Since the physical output during attacks was found to be mostly unrelated to situational context, the importance of being sufficiently recovered for upcoming attacks or well-timed substitutions of players who are unable to increase their physical output anymore, is also emphasised.

5.2.4 Conclusion

The current observational study found relations between running behaviour and the outcome of scoring attempts. Increased distances covered during the attacks by both the attacker, looking to move away from his opponent, and the defender, having to track his opponent, were found to be related to a higher attacking effectiveness. Counter attacks, characterised by fewer defenders behind the ball, were found to be more physically demanding in comparison with direct play and elaborate attacks and lead to most goals scored. Since a decreased physical output during the match and in the 5-min period leading up to an attempt was found to relate to success, the importance of a great physical capacity is demonstrated. Consequently, tactical as well as pacing strategies are shown to be of significance, in order to increase one's physical output when required. Furthermore, space, available during counter attacks or created by attackers through increased running output, may be a decisive factor during GSOs from open play. Future, large-scale, studies may confirm these results from applied data and analyses.

Chapter 6

Practical steps towards improving attacking effectiveness

6.1 Summary of results

By determining how players behave during successful attacking sequences, this research programme diverged its focus as far as practically possible. With that, it only seems logical to once again follow the feedback loop and consider how the collected data and results can answer the very first question that led to this programme: "When goals are most important to win a match; how to transform an attack into a goal?". Because, again, no matter how you spin it, whether you want to concede fewer goals or score more goals than your opponent, you have to end up outscoring your opponent.

From the first study included in this research programme, it has become clear that context plays a vital role in the concept of playing effectiveness and scoring goals. Football is an interactive sport, with endless spatial constellations of ball and players (Hughes and Bartlett, 2002). That said, general patterns within these contextual boundaries may be sought and support practitioners in preparation of or during a match. Since these practitioners are usually employed by a club and working for a single team, the (individual) context becomes clearer and more important. The characteristics of a single player or the playing style of a single team are easier to define in comparison with that from a complete league or even a multitude of leagues (Bradley and Ade, 2018).

Apart from this contextualisation, the first study also immediately directed the focus of the current programme on "space". Not the great intergalactic universe above our heads, but the spatial characteristic of having distance between oneself and the next closest opponent. Players were found to be able to execute their plan of aiming and shooting regardless of obstacles in their path towards the goal. However, they do need time to plan their actions and set up for an attempt. This time equals space, when considering that opponents will try to close down on players with the possibility of, tactically speaking, threatening their goalkeeper.

Consequently, when gaining space is the target, players have to move away from their opponent. Because, theoretically, with both teams starting with ten outfield players, balance exists and every player has an opponent capable of covering their tracks (Tenga et al., 2010a). The second study of this programme focussed on this inter-team balance and when it may be disturbed during an attack. This investigation did not reveal any specific types of play or constellations of players and opponents mostly responsible for the creation of GSOs. However, an indication towards the impact of a defender's missed interception on inter-team balance was found, which seems in line with other studies, describing the significance of asynchronic movements (Goes et al., 2020; Moura et al., 2016). Furthermore, balance was repeatedly deemed to be disturbed around five seconds prior to the attempt, highlighting a rapid chain reaction of events prior to a GSO. On top of that, experts showed stronger agreements for attempts that were converted into goals, although they were unaware of the outcome. This finding indicates a potential effect of the severity of the disturbance and, thereby, it appears players can aim to create the greatest disturbance as possible. The question how they could achieve this, led to the design of the final study. Here, the acute behaviour of the players during attacking sequences leading to GSOs and its influence on the effectiveness were investigated.

After validating the accuracy of the tracking system, which the participating sub-elite team could afford to use, season-long physical, tactical and situational data was collected. Apart from confirming previous results of distinctions between playing styles, with higher speeds and effectiveness recorded during counter attacks (Lago et al., 2010; Sarmento et al., 2018), improved attacking effectiveness was found for increased spaces and player activity as well as a lower taxing of their physical capacity. This again confirms the importance of space, since attackers need to move away from their opponent. The more offensive players move, the more difficult it becomes for the defenders to track them and prevent an attempt at goal. Furthermore, with increased activities of defenders prior to a shot, greater likelihoods of them allowing threatening attempts at goal were found. Thus, whilst space is a crucial aspect in scoring goals, attackers need to be able to create and utilise it and defenders need to be able to close it down in time. As such, the value of a superior physical capacity is highlighted, obviously linked with the tactical insights and qualities to be at the right place at the right time (Longo et al., 2019). This can be traced back to previous findings, where players in higher leagues did not run more during a game in comparison with lower league players (Bradley et al., 2013a), but they showed a greater capacity and were able to increase their output when required (Dellal et al., 2011). In case the physical battery of a player runs out during a match, well-timed substitutions become important (Bradley et al., 2014). From an attacking perspective, to benefit from the so-called "fresh legs" and create spaces that the fatigued opponents cannot close. When taking a defensive point of view, the introduction of fit players may aid to remain in balance with teammates and the opposition. This to minimise spaces for attackers to utilise (Tenga et al., 2010a). Since match data (describing both notational events and physical parameters) is often available live in elite settings, for both the own team and the opponent, practitioners could also make use of the physical player data to alter and optimise attacking or defensive tactics.

6.2 Practical implications

With that, a start towards practical implications of the results from the current research programme is given. Such approaches, utilising time-motion data with scientific backing, may increase the weight of the support given to coaches and the field of applied science in general. Scientific studies often seem to answer questions, practitioners or coaches never asked. Thereby, applied practice has to be flexible and alterations to general scientific guidelines should be designed. Studies might not always have to focus on large-scale investigations, to be able to generalise the results and apply them to a large population. Showing how science can support a single team and provide ways to specify data without losing power, may be more useful in certain situations. In the case of the current research programme, it was not studied what separates a successful team from a less successful team, but what makes a goal a goal and how the data available can support this quest in practice. Therefore, this programme focussed on direct interpretations of attacking threat; a feature that every team or player could utilise to improve their offensive and defensive play.

From the first study on, the contextualisation of match data proved essential for analyses. By incorporating available measures, like distance to opponents or shooting angles, the specificity of applied analyses may be enhanced. When match-like scenarios are replicated or at least considered, training focus or drills may be more effective, leading to improved match preparations (Ade et al., 2016). With the results from the first study, goal scoring practice or defending strategies may also be optimised, when specific shooting characteristics and preferences are known from future opponents.

Similar to the incorporation of context, the second study revealed the practical possibilities when investigating the phases leading up to game changing events. Instead of describing the final event or even those one or two steps backwards, the reason why the event took place may remain unclear. The description of inter-team (defensive) balance was found to be reliable when described by an expert observer. In a team environment, this means an analyst or coach may qualitatively analyse those sequences leading to goals or GSOs. Both from an offensive, as well as defensive point of view. With this, successful styles of play or weaknesses in the own or opponent's defensive organisation may be identified, which in turn could optimise training and preparation.

The final study of this research programme focussed on what individual player characteristics affected the outcome of an attacking sequence, potentially providing aspects which can be altered during a match or optimised in training. The findings of an increased physical output (described by a greater distance covered and intensity) during successful attacks provides a general emphasis for a great physical capacity. A player should not (necessarily) empty it every game, however, they should be able to increase their work rate whenever required (Dellal et al., 2011). From a tactical point of view, the increased running output of the attackers show they need (to learn) to create space for themselves during an attack. Consequently, defenders should improve their tracking abilities and their spatial awareness to know when they should close the gap without opening up space in behind. Because, in line with the second study, missed interceptions may prove detrimental to the defensive stability and allow for more opposing attacking threat. For practitioners and coaches, the timing of substitutions can be objectified when taking the (estimated) physical batteries of the own or opponent's players into account. Specifically, detailed physical information about the own players should be known from testing and training. Since that data may not be widely available for opponent players, previous physical match performances may provide indications for their physical state during a match.

Ultimately, whenever applying scientific results into practice, the context of those studies is of significance. As said before, this programme has it premises on an applied approach. Results are based on data from a single team or small-scale studies. It might not be the same for any given team, however, it does show what can be done with the data available. Also, many other choices could have been made or directions could have been taken. Instead of looking at physical parameters, spatial parameters could have been studied more intensively. However, different time-motion systems are required to run such studies, compared to the GPS system currently utilised. For this research programme, a chance to implement a GPS system within a sub-elite, but professional team presented itself, which was taken. Thereby, metrics describing positional interactions were not as useful. First, because of the limited positional accuracy of GPS and, second, because opponent data was not available. An application of a similar setup within an elite team, would most likely not have presented the same flexibility with time-motion data as well as tactical insights and knowledge which was provided for the current research. Any practitioner could, or even should, make these considerations for themselves and design the study or approach best suited for their team or context.

6.3 Future research directions

That said, where practical applications may present direct solutions for single teams, it is more difficult for practitioners to develop ground-breaking scientific frameworks. However, as stated before, science and practice should complement each other. By starting with practical questions, scientific methods may be composed to answer those and potentially other related topics. In case of the current research programme; sports and data scientists could focus on the development of computer learning solutions. Such methods, capable of taking all possible confounders into consideration for endlessly large datasets, may ultimately allow for flexible and specific applications (Herold et al., 2019). This would present possibilities to offer a multitude of applied solutions (Rein and Memmert, 2016). This seems more feasible than large multi-team or multi-league comparisons which present little value in a team environment, where improving individual qualities and player characteristics is key.

When taking the results of the first study into consideration, the positional aspects of context only explained a limited variation of shooting outcome. And since players are always in motion, more detailed and comprehensive studies could be performed to determine the effect of bodily orientation on shooting performance (Buchheit and Simpson, 2017). Because similar to practitioners, scientists would also benefit from more advanced and specific solutions to analyse game-changing events. The more coaches and players benefit from it, the higher the likelihood that attention increases and subsequent financial growth follows.

Similarly, from the second study of the current research programme, the qualitative aspects of the practical approach may be combined with a more scientific quantitative method. This means, upscaling the research and linking the findings to larger databases, however, without losing focus on an individual application. The interesting characteristic of the concept of inter-team balance is that many more disturbances might occur during a match, which do not lead to palpable events like GSOs (Goes et al., 2020). For a practitioner, these events are potentially impossible to singlehandedly retrieve and analyse. Scientific solutions could widen this search and thereby offer highly interesting opportunities for practice to evolve. In the end, that is arguably the role of scientific support.

The same goes for the final study. With all potential aspects of time-motion data, especially when opponent data is available too, far too many parameters are available for a practitioner to investigate. A computerised solution could make use of the current qualitative findings and guide a quantitative solution. This could also include data from elite teams, making the data more interesting for the teams that have scientific support staff in place. This directly shows the previously described intent and usefulness of studies in sub-elite environments, where it may showcase potential applications within elite environments, without having to use their valuable time and data for so-called practice runs.

Taken together, with spaces created being the aspect linking all studies together, future scientific approaches may zoom in on this aspect more closely. How much space is generally required, which player requires more space for a successful action or which player is not affected by opponents stepping on his toes? Which players or teams are effective in creating or utilising space and what can practitioners learn from their playing styles? Questions like these would actually arise from within elite environments and with the support of a rigorous scientific investigation, the results from such studies would carry a lot of weight in practice and thereby science.

6.4 Take home messages

Throughout the current research programme, regardless of whether you agree with the methods or analyses, it has been shown how practitioners could apply match data in the field. By building on a scientific base, the data may be used with confidence, adding strength to the application and following messages to coaches or players. It is this base, that makes applied science such a valuable field within elite sports. Interpreting, explaining or presenting data as one likes, without a direct association with the level of performance, can lead to skewed conclusions or even flawed approaches in training and matches. With the financial stakes at play, such subjective actions may well endanger long-term success. Therefore, it seems worthwhile to keep the analyses as close to real life situations, by incorporating context and investigating those aspects of performance that matter to your team. It is only then, that useful and objective information may be gathered, which have a higher likelihood of being accepted by players, coaches or directors. Or even fans for that matter, who are in the end the sole reason for the financial possibilities within elite sporting environments. Science should not be a loaded term, it should give strength to the findings from applied analyses.

Because in the end, when working with a single team, it is the role of the applied practitioner to improve the performances of one's own players. Comparing them with what an average player in a general or even selected league might be capable of doing, gives a false sense of progress. Football is highly interactive. With all players having different ideas, performing diverse roles or interpreting various tactical plans differently, their behaviour will be affected accordingly. Simply aiming to be better than average, will most likely not lead to optimal performances. In order to increase the effectiveness of a player or a team, it should be kept in mind that the players and all constellations are unique and the analyses should be too. Working within a team or with an individual player requires one to thoroughly analyse their actions and put them in greater perspective if desired. However, at the same time, these analyses should also remain practical and connected to the players' own performances and the simple fact whether a team or player improves. By adding context to analyses, the trust in the results may be strengthened, leading to a greater impact of the findings. It is the ultimate challenge to support and facilitate improvements in training, preparation and finally the actual level of match performance. A critical way of thinking and applying what is available may be anyone's best way forward.

References

1. Abt, G. and Lovell, R. (2009) The use of individualized speed and intensity thresholds for determining the distance run at high-intensity in professional soccer. *J Sports Sci* **27,** 893-8, Jul.

2. Ade, J., Fitzpatrick, J. and Bradley, P.S. (2016) High-intensity efforts in elite soccer matches and associated movement patterns, technical skills and tactical actions. Information for position-specific training drills. *J Sports Sci* **34,** 2205-2214, Dec.

3. Ali, A., Williams, C., Hulse, M., Strudwick, A., Reddin, J., Howarth, L., Eldred, J., Hirst, M. and McGregor, S. (2007) Reliability and validity of two tests of soccer skill. *J Sports Sci* **25,** 1461-70, Nov.

4. Andersson, P., Edman, J. and Ekman, M. (2005) Predicting the World Cup 2002 in soccer: Performance and confidence of experts and non-experts. *Int J Forecast* **21,** 565-576.

5. Anzer, G. and Bauer, P. (2021) A Goal Scoring Probability Model for Shots Based on Synchronized Positional and Event Data in Football (Soccer). *Front Sports Act Living* **3,** 624475.

6. Aquino, R., Munhoz Martins, G.H., Palucci Vieira, L.H. and Menezes, R.P. (2017) Influence of Match Location, Quality of Opponents, and Match Status on Movement Patterns in Brazilian Professional Football Players. *J Strength Cond Res* **31,** 2155-2161, Aug.

7. Bangsbo, J., Mohr, M. and Krustrup, P. (2006) Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci* **24,** 665-74, Jul.

8. Bangsbo, J., Nørregaard, L. and Thorsoe, F. (1991) Activity profile of competition soccer. *Can J Sport Sci* **16,** 110-116.

9. Barrett, S., Midgley, A.W., Towlson, C., Garrett, A., Portas, M. and Lovell, R. (2016) Within-Match PlayerLoad Patterns During a Simulated Soccer Match: Potential Implications for Unit Positioning and Fatigue Management. *Int J Sports Physiol Perform* **11,** 135-40, Jan.

10. Beato, M., Bartolini, D., Ghia, G. and Zamparo, P. (2016) Accuracy of a 10 Hz GPS Unit in Measuring Shuttle Velocity Performed at Different Speeds and Distances (5 - 20 M). *J Hum Kinet* **54,** 15-22, Dec 01.

11. Beato, M., Coratella, G., Stiff, A. and Iacono, A.D. (2018) The Validity and Between-Unit Variability of GNSS Units (STATSports Apex 10 and 18 Hz) for Measuring Distance and Peak Speed in Team Sports. *Front Physiol* **9,** 1288.

12. Bishop, D., Spencer, M., Duffield, R. and Lawrence, S. (2001) The validity of a repeated sprint ability test. *J Sci Med Sport* **4,** 19-29, Mar.

13. Bloomfield, J., Polman, R. and O'Donoghue, P. (2007) Physical Demands of Different Positions in FA Premier League Soccer. *J Sports Sci Med* **6,** 63-70.

14. Bradley, P.S. and Ade, J.D. (2018) Are Current Physical Match Performance Metrics in Elite Soccer Fit for Purpose or Is the Adoption of an Integrated Approach Needed? *Int J Sports Physiol Perform* **13,** 656-664, May 1.

15. Bradley, P.S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., Paul, D., Diaz, A.G., Peart, D. and Krustrup, P. (2011) The effect of playing formation on high-

intensity running and technical profiles in English FA Premier League soccer matches. *J Sports Sci* **29,** 821-30, May.

16. Bradley, P.S., Carling, C., Gomez Diaz, A., Hood, P., Barnes, C., Ade, J., Boddy, M., Krustrup, P. and Mohr, M. (2013a) Match performance and physical capacity of players in the top three competitive standards of English professional soccer. *Hum Mov Sci* **32,** 808-21, Aug.

17. Bradley, P.S., Lago-Penas, C. and Rey, E. (2014) Evaluation of the match performances of substitution players in elite soccer. *Int J Sports Physiol Perform* **9,** 415-24, May.

18. Bradley, P.S., Lago-Penas, C., Rey, E. and Gomez Diaz, A. (2013b) The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *J Sports Sci* **31,** 1261-70.

19. Bradley, P.S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P. and Krustrup, P. (2009) High-intensity running in English FA Premier League soccer matches. *J Sports Sci* **27,** 159-68, Jan 15.

20. Brito Souza, D., López-Del Campo, R., Blanco-Pita, H., Resta, R. and Del Coso, J. (2019) A new paradigm to understand success in professional football: analysis of match statistics in LaLiga for 8 complete seasons. *Int J Perf Anal Sport* **19,** 543-555.

21. Buchheit, M., Allen, A., Poon, T.K., Modonutti, M., Gregson, W. and Di Salvo, V. (2014) Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. *J Sports Sci* **32,** 1844-1857, Dec.

22. Buchheit, M. and Simpson, B.M. (2017) Player-Tracking Technology: Half-Full or Half-Empty Glass? *Int J Sports Physiol Perform* **12,** S235-S241, Apr.

23. Bush, M., Archer, D., Barnes, C., Hogg, B. and Bradley, P. (2016) Longitudinal match performance characteristics of UK and non-UK players in the English Premier League. *Sci Med Football* **1,** 2-9.

24. Bush, M., Barnes, C., Archer, D.T., Hogg, B. and Bradley, P.S. (2015) Evolution of match performance parameters for various playing positions in the English Premier League. *Hum Mov Sci* **39,** 1-11, Feb.

25. Carling, C. (2011) Influence of opposition team formation on physical and skill-related performance in a professional soccer team. *Eur J Sport Sci* **11,** 155-164.

26. Carling, C., Bradley, P., McCall, A. and Dupont, G. (2016) Match-to-match variability in high-speed running activity in a professional soccer team. *J Sports Sci* **34,** 2215-2223, Dec.

27. Carling, C., Le Gall, F. and Dupont, G. (2012) Analysis of repeated high-intensity running performance in professional soccer. *J Sports Sci* **30,** 325-36.

28. Carling, C., Le Gall, F., McCall, A., Nedelec, M. and Dupont, G. (2015) Squad management, injury and match performance in a professional soccer team over a championship-winning season. *Eur J Sport Sci* **15,** 573-82.

29. Carling, C., Reilly, T. and Williams, A.M. (2008) *Performance assessment for field sports*. London: Taylor and Francis.

30. Castellano, J., Alvarez-Pastor, D. and Bradley, P.S. (2014) Evaluation of research using computerised tracking systems (Amisco and Prozone) to analyse physical performance in elite soccer: a systematic review. *Sports Med* **44,** 701-12, May.

31. Castellano, J., Blanco-Villasenor, A. and Alvarez, D. (2011a) Contextual variables and time-motion analysis in soccer. *Int J Sports Med* **32,** 415-21, Jun.

32. Castellano, J., Casamichana, D., Calleja-Gonzalez, J., Roman, J.S. and Ostojic, S.M. (2011b) Reliability and Accuracy of 10 Hz GPS Devices for Short-Distance Exercise. *J Sports Sci Med* **10,** 233-4.

33. Castellano, J., Casamichana, D. and Lago, C. (2012) The Use of Match Statistics that Discriminate Between Successful and Unsuccessful Soccer Teams. *J Hum Kinet* **31,** 139-47, Mar.

34. Chmura, P., Andrzejewski, M., Konefal, M., Mroczek, D., Rokita, A. and Chmura, J. (2017) Analysis of Motor Activities of Professional Soccer Players during the 2014 World Cup in Brazil. *J Hum Kinet* **56,** 187-195, Feb.

35. Collet, C. (2013) The possession game? A comparative analysis of ball retention and team success in European and international football, 2007-2010. *J Sports Sci* **31,** 123-36.

36. Comrey, A.L. and Lee, H.B. (2013) *A first course in factor analysis*. Hillsdale: Erlbaum.

37. Coutts, A.J. and Duffield, R. (2010) Validity and reliability of GPS devices for measuring movement demands of team sports. *J Sci Med Sport* **13,** 133-5, Jan.

38. Dalen, T., Ingebrigtsen, J., Ettema, G., Hjelde, G.H. and Wisloff, U. (2016) Player Load, Acceleration, and Deceleration During Forty-Five Competitive Matches of Elite Soccer. *J Strength Cond Res* **30,** 351-9, Feb.

39. Dellal, A., Chamari, K., Wong, D.P., Ahmaidi, S., Keller, D., Barros, R.M., Bisciotti, G.N. and Carling, C. (2011) Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *Eur J Sport Sci* **11,** 51-59.

40. Di Salvo, V., Baron, R., Tschan, H., Calderon Montero, F.J., Bachl, N. and Pigozzi, F. (2007) Performance characteristics according to playing position in elite soccer. *Int J Sports Med* **28,** 222-7, Mar.

41. Di Salvo, V., Collins, A., McNeill, B. and Cardinale, M. (2006) Validation of Prozone ®: A new video-based performance analysis system. *Int J Perf Anal Sport* **6,** 108-119.

42. Di Salvo, V., Pigozzi, F., Gonzalez-Haro, C., Laughlin, M.S. and De Witt, J.K. (2013) Match performance comparison in top English soccer leagues. *Int J Sports Med* **34,** 526-32, Jun.

43. Duffield, R., Reid, M., Baker, J. and Spratford, W. (2010) Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *J Sci Med Sport* **13,** 523-5, Sep.

44. Duthie, G., Pyne, D. and Hooper, S. (2003) The reliability of video based time motion analysis. *J Hum Mov Stud* **44,** 259-71.

45. Dwyer, D.B. and Gabbett, T.J. (2012) Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes. *J Strength Cond Res* **26,** 818-24, Mar.

46. Earp, J.E. and Newton, R.U. (2012) Advances in electronic timing systems: considerations for selecting an appropriate timing system. *J Strength Cond Res* **26,** 1245-8, May.

47. Edgecomb, S.J. and Norton, K.I. (2006) Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football. *J Sci Med Sport* **9,** 25-32, May.

48. Faude, O., Koch, T. and Meyer, T. (2012) Straight sprinting is the most frequent action in goal situations in professional football. *J Sports Sci* **30,** 625-31.

49. Fernandez-Navarro, J., Fradua, L., Zubillaga, A., Ford, P.R. and McRobert, A.P. (2016) Attacking and defensive styles of play in soccer: analysis of Spanish and English elite teams. *J Sports Sci* **34,** 2195-2204, Dec.

50. Floor-Westerdijk, M.J., Schepers, H.M., Veltink, P.H., van Asseldonk, E.H. and Buurke, J.H. (2012) Use of inertial sensors for ambulatory assessment of center-of-mass displacements during walking. *IEEE Trans Biomed Eng* **59,** 2080-4, Jul.

51. Franks, I. and Goodman, D. (1986) A systematic approach to analysing sports performance. *J Sports Sci* **4,** 49-59.

52. Fransson, D., Krustrup, P. and Mohr, M. (2016) Running intensity fluctuations indicate temporary performance decrement in top-class football. *Sci Med Football* **1,** 10-17.

53. Frencken, W.G., Lemmink, K.A. and Delleman, N.J. (2010) Soccer-specific accuracy and validity of the local position measurement (LPM) system. *J Sci Med Sport* **13,** 641-5, Nov.

54. Gaudino, P., Iaia, F.M., Alberti, G., Strudwick, A.J., Atkinson, G. and Gregson, W. (2013) Monitoring training in elite soccer players: systematic bias between running speed and metabolic power data. *Int J Sports Med* **34,** 963-8, Nov.

55. Goes, F.R., Brink, M.S., Elferink-Gemser, M.T., Kempe, M. and Lemmink, K. (2020) The tactics of successful attacks in professional association football: large-scale spatiotemporal analysis of dynamic subgroups using position tracking data. *J Sports Sci* 1-10, Oct 27.

56. Gonzalez-Rodenas, J., Lopez-Bondia, I., Calabuig, F., James, N. and Aranda, R. (2015) Association between playing tactics and creating scoring opportunities in elite football. A case study in Spanish Football National Team. *J Hum Sport Exerc* **10**.

57. Gonzalez-Rodenas, J., Mitrotasios, M., Aranda, R. and Armatas, V. (2020) Combined effects of tactical, technical and contextual factors on shooting effectiveness in European professional soccer. *Int J Perf Anal Sport* **20,** 280-293.

58. Gréhaigne, J.F., Mahut, B. and Fernandez, A. (2001) Qualitative observation tools to analyse soccer. *Int J Perf Anal Sport* **1,** 52-61.

59. Harper, D.J. and Kiely, J. (2018) Damaging nature of decelerations: Do we adequately prepare players? *BMJ Open Sport Exerc Med* **4,** e000379.

60. Harper, L.D., West, D.J., Stevenson, E. and Russell, M. (2014) Technical performance reduces during the extra-time period of professional soccer match-play. *PLoS One* **9,** e110995.

61. Haugen, T. and Buchheit, M. (2016) Sprint Running Performance Monitoring: Methodological and Practical Considerations. *Sports Med* **46,** 641-56, May.

62. Haugen, T.A., Tonnessen, E., Svendsen, I.S. and Seiler, S. (2014) Sprint time differences between single- and dual-beam timing systems. *J Strength Cond Res* **28,** 2376-9, Aug.

63. Herold, M., Goes, F., Nopp, S., Bauer, P., Thompson, C. and Meyer, T. (2019) Machine learning in men's professional football: Current applications and future directions for improving attacking play. *Int J Sports Sci Coach* **14,** 798-817.

64. Hopkins, W.G., Marshall, S.W., Batterham, A.M. and Hanin, J. (2009) Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* **41,** 3-13, Jan.

65. Hoppe, M.W., Baumgart, C., Polglaze, T. and Freiwald, J. (2018) Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports. *PLoS One* **13,** e0192708.

66. Hoppe, M.W., Slomka, M., Baumgart, C., Weber, H. and Freiwald, J. (2015) Match Running Performance and Success Across a Season in German Bundesliga Soccer Teams. *Int J Sports Med* **36,** 563-6, Jun.

67. Hughes, M. and Franks, I. (2005) Analysis of passing sequences, shots and goals in soccer. *J Sports Sci* **23,** 509-14, May.

68. Hughes, M.D. and Bartlett, R.M. (2002) The use of performance indicators in performance analysis. *J Sports Sci* **20,** 739-54, Oct.

69. Hunter, F., Bray, J., Towlson, C., Smith, M., Barrett, S., Madden, J., Abt, G. and Lovell, R. (2015) Individualisation of time-motion analysis: a method comparison and case report series. *Int J Sports Med* **36,** 41-8, Jan.

70. Ingebrigtsen, J., Dalen, T., Hjelde, G.H., Drust, B. and Wisloff, U. (2015) Acceleration and sprint profiles of a professional elite football team in match play. *Eur J Sport Sci* **15,** 101-10.

71. Jennings, D., Cormack, S., Coutts, A.J., Boyd, L. and Aughey, R.J. (2010) The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *Int J Sports Physiol Perform* **5,** 328-41, Sep.

72. Johnston, R.J., Watsford, M.L., Kelly, S.J., Pine, M.J. and Spurrs, R.W. (2014) Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res* **28,** 1649-55, Jun.

73. Kaiser, H.F. (1960) The application of electronic computers to factor analysis. *Educ Psychol Meas* **20,** 141-151.

74. Kempe, M., Vogelbein, M., Memmert, D. and Nopp, S. (2014) Possession vs. Direct Play: Evaluating Tactical Behavior in Elite Soccer. *Int J Sports Sci* **9,** 13.

75. Lago, C. (2009) The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *J Sports Sci* **27,** 1463-9, Nov.

76. Lago, C., Casais, L., Dominguez, E. and Sampaio, J. (2010) The effects of situational variables on distance covered at various speeds in elite soccer. *Eur J Sport Sci* **10,** 103-109.

77. Lago-Ballesteros, J. and Lago-Peñas, C. (2010) Performance in Team Sports: Identifying the Keys to Success in Soccer. *J Hum Kinet* **25,** 85-91.

78. Lago-Ballesteros, J., Lago-Penas, C. and Rey, E. (2012) The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. *J Sports Sci* **30,** 1455-61.

79. Lago-Peñas, C. and Dellal, A. (2010) Ball Possession Strategies in Elite Soccer According to the Evolution of the Match-Score: the Influence of Situational Variables. *J Hum Kinet* **25,** 93-100.

80. Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A. and Gómez, M. (2010) Game-Related Statistics that Discriminated Winning, Drawing and Losing Teams from the Spanish Soccer League. *J Sports Sci Med* **9,** 288–293.

81. Lames, M. and McGarry, T. (2007) On the search for reliable performance indicators in game sports. *Int J Perf Anal Sport* **7,** 62-79.

82. Landis, J.R. and Koch, G.G. (1977) The measurement of observer agreement for categorical data. *Biometrics* **33,** 159-74.

83. Larsson, P. (2003) Global positioning system and sport-specific testing. *Sports Med* **33,** 1093-101.

84. Link, D. and de Lorenzo, M.F. (2016) Seasonal Pacing - Match Importance Affects Activity in Professional Soccer. *PLoS One* **11,** e0157127.

85. Link, D., Lang, S. and Seidenschwarz, P. (2016) Real Time Quantification of Dangerousity in Football Using Spatiotemporal Tracking Data. *PLoS One* **11,** e0168768.

86. Linke, D., Link, D. and Lames, M. (2018) Validation of electronic performance and tracking systems EPTS under field conditions. *PLoS One* **13,** e0199519.

87. Linke, D., Link, D. and Lames, M. (2020) Football-specific validity of TRACAB's optical video tracking systems. *PLoS One* **15,** e0230179.

88. Liu, H., Gomez, M.A., Goncalves, B. and Sampaio, J. (2016) Technical performance and match-to-match variation in elite football teams. *J Sports Sci* **34,** 509-18.

89. Longo, U.G., Sofi, F., Candela, V., Dinu, M., Cimmino, M., Massaroni, C., Schena, E. and Denaro, V. (2019) Performance Activities and Match Outcomes of Professional Soccer Teams during the 2016/2017 Serie A Season. *Medicina* **55**, Aug 12.

90. Mackenzie, R. and Cushion, C. (2013) Performance analysis in football: a critical review and implications for future research. *J Sports Sci* **31,** 639-76.

91. Malone, J.J., Lovell, R., Varley, M.C. and Coutts, A.J. (2017) Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *Int J Sports Physiol Perform* **12,** S218-S226, Apr.

92. Mayhew, S.R. and Wenger, H.A. (1985) Time–motion analysis of professional soccer. *J Hum Mov Stud* **11,** 49-52.

93. Mitrotasios, M. and Armatas, V. (2014) Analysis of Goal Scoring Patterns in the 2012 European Football Championship. *Sport J* 1-11.

94. Mohr, M., Krustrup, P. and Bangsbo, J. (2003) Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci* **21,** 519-28, Jul.

95. Moura, F.A., van Emmerik, R.E., Santana, J.E., Martins, L.E., Barros, R.M. and Cunha, S.A. (2016) Coordination analysis of players' distribution in football using cross-correlation and vector coding techniques. *J Sports Sci* **34,** 2224-2232, Dec.

96. Paul, D.J., Bradley, P.S. and Nassis, G.P. (2015) Factors affecting match running performance of elite soccer players: shedding some light on the complexity. *Int J Sports Physiol Perform* **10,** 516-9, May.

97. Petersen, C., Pyne, D., Portus, M. and Dawson, B. (2009) Validity and reliability of GPS units to monitor cricket-specific movement patterns. *Int J Sports Physiol Perform* **4,** 381-93, Sep.

98. Pollard, R. and Gómez, M.A. (2014) Components of home advantage in 157 national soccer leagues worldwide. *Int J Sport Exerc Psychol* **12,** 218-233.

99. Pollard, R. and Reep, C. (1997) Measuring the effectiveness of playing strategies at soccer. *J R Stat Soc* **46,** 541-550.

100. Pollard, R., Reep, C. and Hartley, S. (1988) The quantitative comparison of playing styles in soccer. In: *Science and Football*. Ed: T. Reilly, A.L., K. Davids and W. J. Murphy. London: Spon. 309-315.

101. Rampinini, E., Alberti, G., Fiorenza, M., Riggio, M., Sassi, R., Borges, T.O. and Coutts, A.J. (2015) Accuracy of GPS devices for measuring high-intensity running in field-based team sports. *Int J Sports Med* **36,** 49-53, Jan.

102. Randers, M.B., Mujika, I., Hewitt, A., Santisteban, J., Bischoff, R., Solano, R., Zubillaga, A., Peltola, E., Krustrup, P. and Mohr, M. (2010) Application of four different football match analysis systems: a comparative study. *J Sports Sci* **28,** 171-82, Jan.

103. Rathke, A. (2017) An examination of expected goals and shot efficiency in soccer. *J Hum Sport Exerc* **12,** 514-529.

104. Reep, C. and Benjamin, B. (1968) Skill and Chance in Association Football. *J R Stat Soc* **131,** 581-585.

105. Reilly, T. and Thomas, V. (1979) Estimated daily energy expenditures of professional association footballers. *Ergonomics* **22,** 541-8, May.

106. Rein, R. and Memmert, D. (2016) Big data and tactical analysis in elite soccer: future challenges and opportunities for sports science. *Springerplus* **5,** 1410.

107. Ruiz, H., Lisboa, P.J., Neilson, P.J. and Gregson, W. (2015) *Measuring scoring efficiency through goal expectancy estimation*. Bruges.

108. Sarmento, H., Bradley, P., Anguera, M.T., Polido, T., Resende, R. and Campanico, J. (2016) Quantifying the offensive sequences that result in goals in elite futsal matches. *J Sports Sci* **34,** 621-9.

109. Sarmento, H., Figueiredo, A., Lago-Penas, C., Milanovic, Z., Barbosa, A., Tadeu, P. and Bradley, P.S. (2018) Influence of Tactical and Situational Variables on Offensive Sequences During Elite Football Matches. *J Strength Cond Res* **32,** 2331-2339, Aug.

110. Sarmento, H., Marcelino, R., Anguera, M.T., CampaniCo, J., Matos, N. and LeitAo, J.C. (2014) Match analysis in football: a systematic review. *J Sports Sci* **32,** 1831-1843, Dec.

111. Schimpchen, J., Gopaladesikan, S. and Meyer, T. (2021) The intermittent nature of player physical output in professional football matches: An analysis of sequences of peak intensity and associated fatigue responses. *Eur J Sport Sci* **21,** 793-802, Jun.

112. Schulze, E., Clemens, C., Nopp, S. and Meyer, T. (2019) Defensive Balance in Elite Football: Exploring the Development of Goal Scoring Opportunities. *Sport Perf Sci Reports* **60,** 1-3.

113. Schulze, E., Julian, R. and Skorski, S. (2021) The Accuracy of a Low-Cost GPS System during Football-Specific Movements. *J Sports Sci Med* **20,** 126-132, Mar.

114. Schutz, Y. and Herren, R. (2000) Assessment of speed of human locomotion using a differential satellite global positioning system. *Med Sci Sports Exerc* **32,** 642-6, Mar.

115. Scott, M.T., Scott, T.J. and Kelly, V.G. (2016) The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *J Strength Cond Res* **30,** 1470-90, May.

116. Seay, J.F., Van Emmerik, R.E. and Hamill, J. (2011) Low back pain status affects pelvis-trunk coordination and variability during walking and running. *Clin Biomech* **26,** 572-8, Jul.

117. Stevens, T.G., de Ruiter, C.J., van Niel, C., van de Rhee, R., Beek, P.J. and Savelsbergh, G.J. (2014) Measuring acceleration and deceleration in soccer-specific movements using a local position measurement (LPM) system. *Int J Sports Physiol Perform* **9,** 446-56, May.

118. Tenga, A., Holme, I., Ronglan, L.T. and Bahr, R. (2010a) Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. *J Sports Sci* **28,** 245-55, Feb.

119. Tenga, A., Holme, I., Ronglan, L.T. and Bahr, R. (2010b) Effect of playing tactics on goal scoring in Norwegian professional soccer. *J Sports Sci* **28,** 237-44, Feb.

120. Tenga, A., Kanstad, D., Ronglan, L.T. and Bahr, R. (2009) Developing a New Method for Team Match Performance Analysis in Professional Soccer and Testing its Reliability. *Int J Perf Anal Sport* **9,** 8-25.

121. Tenga, A., Ronglan, L.T. and Bahr, R. (2010c) Measuring the effectiveness of offensive match-play in professional soccer. *Eur J Sport Sci* **10,** 269-277.

122. Trewin, J.M., C.; Varley, M. C.; Cronin, J. (2017) The influence of situational and environmental factors on match-running in soccer: a systematic review. *Sci Med Football* **1,** 183-194.

123. Vach, W. (2005) The dependence of Cohen's kappa on the prevalence does not matter. *J Clin Epidemiol* **58,** 655-61, Jul.

124. Varley, M.C., Jaspers, A., Helsen, W.F. and Malone, J.J. (2017) Methodological Considerations When Quantifying High-Intensity Efforts in Team Sport Using Global Positioning System Technology. *Int J Sports Physiol Perform* **12,** 1059-1068, Sep.

125. Vogelbein, M., Nopp, S. and Hokelmann, A. (2014) Defensive transition in soccer - are prompt possession regains a measure of success? A quantitative analysis of German Fussball-Bundesliga 2010/2011. *J Sports Sci* **32,** 1076-83.

Curriculum Vitae

The curriculum vitae was removed from the electronic version of the doctoral thesis for reasons of data protection.

Appendices

PDFs of Publications

Science and Medicine in Football

ISSN: 2473-3938 (Print) 2473-4446 (Online) Journal homepage: https://www.tandfonline.com/loi/rsmf20

Effects of positional variables on shooting outcome in elite football

Emiel Schulze, Bruno Mendes, Nuno Maurício, Bruno Furtado, Nuno Cesário, Sandro Carriço & Tim Meyer

To cite this article: Emiel Schulze, Bruno Mendes, Nuno Maurício, Bruno Furtado, Nuno Cesário, Sandro Carriço & Tim Meyer (2018) Effects of positional variables on shooting outcome in elite football, Science and Medicine in Football, 2:2, 93-100, DOI: 10.1080/24733938.2017.1383628

To link to this article: https://doi.org/10.1080/24733938.2017.1383628

Published online: 04 Oct 2017.

This publication was removed from the electronic version of the doctoral thesis for copyright purposes. DOI: https://doi.org/10.1080/24733938.2017.1383628.

Defensive Balance in Elite Football: Exploring the Development of Goal Scoring Opportunities

Emiel Schulze [1], **Christofer Clemens** [2], **Stephan Nopp** [2 3] **and Tim Meyer** [1]

[1]Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany,[2]Deutscher Fußball-Bund, Frankfurt am Main, Germany, and [3]3. Institute of Cognitive and Team/Racket Sport Research, German Sport University, Cologne, Germany

Team-sport | Balance | Goal Scoring opportunities | Analysis

Headline

In association football (soccer), both teams start with ten outfield players and a goalkeeper, which suggests that balance exists between them. In order to create space for goal scoring opportunities (GSOs; shooting attempts), it was found that this balance has to be disturbed (1, 2). Assessing balance qualitatively may provide insights into playing effectiveness in a time-efficient and accessible fashion. Furthermore, practitioners do not have to rely on fixed events, such as shots or possessions, potentially improving the flexibility of analyses (3).

Aims of the paper

In order to determine the applicability of such an approach, the present study aimed to explore defensive balance in a qualitative manner. By having experts observe and rate the between-team balance during match events leading up to GSOs, it was aimed to determine whether the concept can be validly described and applied by qualified individuals. By collecting the reasons for the occurrence of the GSOs, thus for a loss of balance, typical styles of play affecting balance may become apparent.

Methods

Design. Expert participants completed two experimental trials (case series), in which videos containing attacking sequences were rated for defensive balance in a second-by-second fashion. General questions about each event were answered afterwards to describe the progression of play.

Participants. Eight observers (age: 36±11 yrs; experience with match analysis: 9±6 yrs) participated in the present study. The observers were match analysts or coaches, holding at least a B-level licence from the European Football Association (UEFA). Furthermore, participants had 20±8 yrs of playing experience, ensuring sufficient understanding of tactics in football. The participants provided informed consent before the first trial. The study was ethically approved by the local Human Research Ethics Committee (Ärztekammer Saarland) and performed according to the Declaration of Helsinki.

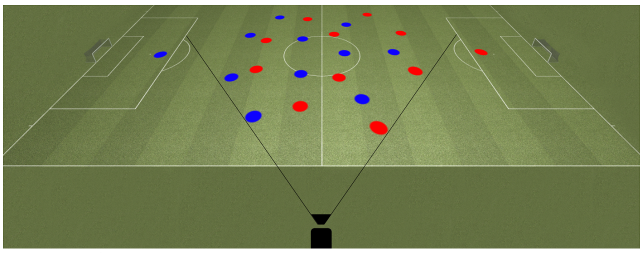

Fig. 1. Graphical representation of the wide-view tactical perspective.

Methodology. In total, 14 sequences ending in a GSO were incorporated. The events were derived from multiple matches played by the German national team and consisted of various build-ups to the GSOs. Five sequences were included in a familiarisation trial and nine were included in the experimental trials. Those nine events were counterbalanced for outcome (goal, save, wide) and build-up (elaborate, direct, counter) (2). A wide-view tactical perspective, wherein all outfield players were constantly in sight, was used as footage (see Figure 1). The events were cut at the moment the ball was last struck and started with the recovery of possession or after maximally 20 seconds of possession. Hereby, the outcome was not identifiable to the observers, preventing possible bias.

The familiarisation trial was performed to ensure full understanding of the concept and procedures. The experimental phase consisted of two trials, during which nine match events were shown in a randomised order. The events were shown in 1-second bouts with a self-controlled pause in between. For every second, a rating had to be given on a 5-point Likert scale (from "very poor" to "very good"; see Figure 2). Afterwards, the observers had to answer three questions: 1) which second in the sequence was crucial (SEC); 2) the offensive play creating the GSO; and 3) the defensive error allowing for the GSO.

To analyse the rating pattern, the slope over every four consecutive ratings of defensive balance was calculated. The ratings were natural log-transformed, making the change from "bad" [2] and "very bad" [1] more detrimental to the balance than that from "very good" [5] and "good" [4]. The largest negative slope was selected as the moment where balance was lost (SLP; see Figure 2). Since the duration of the match events differed, SEC and SLP were computed as continuous time variables counting backwards from the moment of the actual attempt. Thus, both measures described the time (in seconds) before the attempt where defensive balance was deemed to be lost.

Statistical analysis. Outcomes are displayed, where appropriately, as mean and 90% confidence limits [CL]. The validity of the two measures of defensive balance (SEC and SLP) was determined through effect sizes (ES; Cohen's d) (4). Cohen's Kappas (K) were calculated to determine the magnitude of the reliability of all variables (5). A quadratic weighting was chosen for SEC and SLP to emphasize the importance of ratings closer together. For OFF and DEF, a non-weighted approach was used, since the answering options had no relationship to each other.

Results

Balance was found to be lost on average 5.6 [5.0; 6.3] s before the attempt according to SEC and 5.9 [5.4; 6.4] s before the attempt according to SLP (ES=0.3).

Inter-Rater Reliability_. The ratings of defensive balance, described by SLP, showed a moderate between-observer agree-

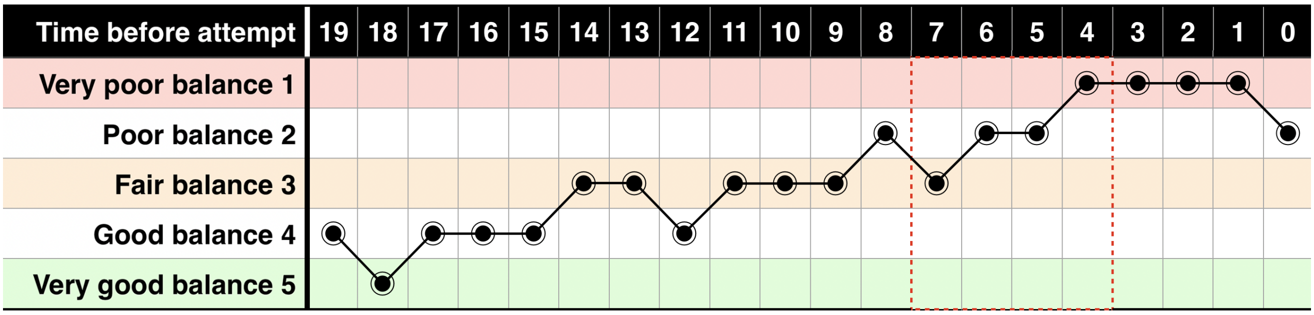

Fig. 2. Second-by-second rating with the most detrimental change highlighted in the red square.

ment (K=0.47). A similar moderate agreement between observers was found for SEC (K=0.50). Finally, when analysing the reasons for the occurrence of the GSO, slight between-observer agreements were found for OFF and DEF (K=0.17 and K=0.11, respectively).

Intra-Rater Reliability. Substantial within-observer agreements were found for SLP and SEC (K=0.72 and K=0.79, respectively). For the reasoning, why the GSOs occurred, the observers showed moderate intra-agreement (K=0.53 for offensive and K=0.40 for defensive reasons). The experience of the observers (years active as coach or analyst) did not substantially affect any of the agreements.

Situational Variables. Observers showed lower agreements in SEC during counter attacks and elaborate build up in comparison with direct passing build up (ES=2.4 and ES=2.8, respectively). Also, a higher between-observer agreement was found for those events that led to a goal (which the observers were unaware of), in comparison with those attempts that were saved or off target (ES=1.2 and ES=1.6, respectively).

Discussion

The present study aimed to determine whether defensive balance in elite football can be reliably distinguished and rated by expert observers. Through the rating of attacking sequences on a second-by-second base, the development of (dis)balance within the defensive organisation was measured. The most detrimental change within the ratings was compared with the selection of the most decisive second by the observers. A small effect was found for both methods, which, in combination with substantial within-observer agreements for both measures, indicates that practitioners are capable of reliably selecting the moment they hold crucial during an attacking sequence.

However, moderate between-observer agreements were found for the development or loss of balance. This indicates that individuals have a different interpretation of the constructs involved in defensive balance, most likely due to the multidimensional nature of the concept (1). Along with limited agreements between the reasons for the occurrence of the GSO, the qualitative approach of the current study does not seem to be suitable to determine what (typical) constellations of player and ball positioning are most effective in disturbing an opponent's organisation and thus creating GSOs.

The slight between-observer agreements found, question whether the proposed parameters are two dimensional (e.g. good or bad). It has been suggested, that tight defensive pressure is an indication of a balanced defence (1). Furthermore, ball interceptions, which require high pressure, were also found to be linked with team success (6). In line with these results, the current study found mistakes in defensive pressure to be crucial (43% of the time). As such, applying pressure by defensive players seems to influence the defensive performance. However, ball interceptions require a move towards the upcoming attacker, thereby mirroring its run towards goal. By failing to succeed in intercepting possession, space opens up for the attack. This, in turn, agrees with the results from Moura and colleagues, which highlight movements in opposite directions (anti-phase coordination) by the defensive and attacking teams before GSOs (7). Thus, high pressure alone does not seem to be sufficient for a balanced defence, when the attacker is able to evade the first defender.

The importance of balance is supported by the fact that higher agreements were found in the current study when the GSO ended in a goal, although the observers were unaware of the outcome. This implies that the severity of the disturbance in balance is greater and thereby less disputable. Thus, it can again be argued that defensive balance indeed affects attacking effectiveness (1). Where the current qualitative approach failed to identify typical styles of play affecting balance, techniques involving machine learning may enable the objective identification of successful patterns of play (8). Such research would be in line with studies relating specific types of play to attacking success (9). However, when relying on changes in balance instead of GSOs, many more sequences will become available, leading to a more detailed description of playing style.

Practical Applications

- A uniform type of play affecting defensive balance was not found, however the present study did show that experts are able to reliably select what they deem to be the decisive second within an attacking sequence.
- This method is the least time consuming of the currently included techniques and the available quantitative approaches describing defensive balance. An individual application of the current approach seems promising from a practical point of view.
- By studying which teams or players are capable of disturbing the balance within an opponent's defence, training and preparation may be improved.

Limitations

- The current study only involved few (nine) sequences observed and rated by a relatively low number of (eight) experts. Future studies could aim to increase this sample size, or, as mentioned before, extrapolate the results of the current and previous studies into an approach involving machine learning.

References

1. Tenga A, Holme I, Ronglan LT and Bahr R. Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. J Sports Sci. 2010; 28: 245-55.

2. Lago-Ballesteros J, Lago-Penas C and Rey E. The effect of playing tactics and situational variables on achieving score-box possessions in a professional soccer team. J Sports Sci. 2012; 30: 1455-61.

3. Tenga A, Ronglan LT and Bahr R. Measuring the effectiveness of offensive match-play in professional soccer. Eur J Sport Sci. 2010; 10: 269-77.

4. Buchheit M. The Numbers Will Love You Back in Return-I Promise. Int J Sports Physiol Perform. 2016; 11: 551-4.

5. Landis JR and Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977; 33: 159-74.

6. Vogelbein M, Nopp S and Hokelmann A. Defensive transition in soccer - are prompt possession regains a measure of success? A quantitative analysis of German Fussball-Bundesliga 2010/2011. J Sports Sci. 2014; 32: 1076-83.

7. Moura FA, van Emmerik RE, Santana JE, Martins LE, Barros RM and Cunha SA. Coordination analysis of players' distribution in football using cross-correlation and vector coding techniques. J Sports Sci. 2016; 34: 2224-32.

8. Link D, Lang S and Seidenschwarz P. Real Time Quantification of Dangerousity in Football Using Spatiotemporal Tracking Data. PLoS One. 2016; 11: e0168768.

9. Sarmento H, Figueiredo A, Lago-Penas C, et al. Influence of Tactical and Situational Variables on Offensive Sequences During Elite Football Matches. J Strength Cond Res. 2018; 32: 2331-9.

©Journal of Sports Science and Medicine (2021) **20,** 126-132
http://www.jssm.org

Research article

The Accuracy of a Low-Cost GPS System during Football-Specific Movements

Emiel Schulze [1]✉, Ross Julian [1,2,3] and Sabrina Skorski [1]
[1] Institute of Sports and Preventive Medicine, Saarland University, Saarbrücken, Germany
[2] Institute of Neuromotor Behavior and Exercise, University of Münster, Münster, Germany
[3] School of Sport and Exercise, Exercise and Sport Research Centre, University of Gloucestershire, England

Abstract
An affordable player monitoring solution could make the evaluation of external loading more accessible across multiple levels of football (soccer). The present study aimed to determine the accuracy of a newly designed and low-cost Global Positioning System (GPS) whilst performing match-specific movement patterns. Sixteen professional male football players (24 ± 3 years) were assigned a GPS device (TT01, Tracktics GmbH, Hofheim, Germany) and completed two experimental trials. In each trial, a continuous protocol including seven movements (sideways cornering, diagonal cornering, accelerating, decelerating, backwards jogging, shuttle running, and skipping) adding up to 500 m, was completed. Time-motion data was compared with criterion distance and velocity (photo-cell timing gates and radar). Validity was assessed through the standard error of the estimate (SEE) and reliability through the coefficient of variation (CV; both with 95% confidence limits). For the total distance covered during the protocol, the system was found to be valid (SEE = 3.1% [2.2; 5.8]) and reliable (intra-device CV = 2.0% [1.2; 7.6]). Similar results were found for velocity (SEE = 3.4% [2.6; 4.8], CV = 4.7% [3.2; 8.5]). In conclusion, the present GPS system, a low-cost solution, was found to be a valid and reliable tool for measuring physical loading during football-specific movements.

Key words: Soccer, team sports, external load, precision, motion analysis.

Introduction

The use of Global Positioning Systems (GPS) within association football (soccer) has grown in recent years (Malone et al., 2017). GPS systems are regarded as an easy-to-administer tracking technology, which is not bound by installment on a single pitch (Buchheit et al., 2014). Prior to July 2015, the use of this technology was restricted to training and friendly matches. It is only after this date, that the world governing body (Fédération Internationale de Football Association; FIFA) permitted the use of wearable technology during official matches. Consequently, this has led to an increase of investigations describing external player load during match play using GPS-monitoring (Martin-Garcia et al., 2018; Torreno et al., 2016).

Most of these reports are based on data collected within professional teams (Trewin et al., 2017). This may possibly be due to financial restrictions of sub-elite teams, who may not be able to afford GPS systems. However, since a greater number of sub-elite players are active in comparison with elite players, a higher standard of (scientific) practice across multiple levels may further develop the sport. In other words, coaches across different levels could be offered objective information to improve match preparation and player selection, ultimately improving the quality of the players.

Although technological developments have led to more advanced tracking solutions within elite environments, they also decreased the costs for basic hardware. This potentially allows for the collection of useful data with less advanced systems in team sport environments (Scott et al., 2016). In order to appropriately interpret the data from such systems, its accuracy has to be tested in ecologically valid situations, independent of the level of the intended users (Malone et al., 2017). This is of particular importance considering that errors were still found to become larger with increasing velocities, despite a greater overall precision for higher sampling rates (Rampinini et al., 2015; Scott et al., 2016).

Subsequently, the aim of the present study was to determine the accuracy of a newly designed and low-cost GPS system. Both time-motion and reference data for distance and velocity were recorded during established football-specific movements.

Methods

Design
Similar to previous studies (Coutts and Duffield, 2010; Hoppe et al., 2018), a continuous protocol including football-specific movements and two criterion measures was performed to analyse the validity and reliability of the collected time-motion data from a GPS system.

Participants
Sixteen male football players (24 ± 3 years, 1.80 ± 0.03 m, 78 ± 4 kg) playing for a professional fourth division team, participated in the study and provided informed consent after the risks and benefits of the study had been explained. The study was ethically approved by the local Human Research Ethics Committee (Ärztekammer Saarland; ref: 23/17) and performed according to the Declaration of Helsinki.

Procedures
The complete study consisted of three different trials. First, a familiarisation trial was performed, followed by two experimental trials to measure validity and reliability. The experimental trials were separated by 14 days, however normal training continued in between.

The protocol consisted of seven types of movements over a 60 m course (see Figure 1), which proportion-

Received: 07 May 2019 / Accepted: 04 January 2021 / Published (online): 01 March 2021

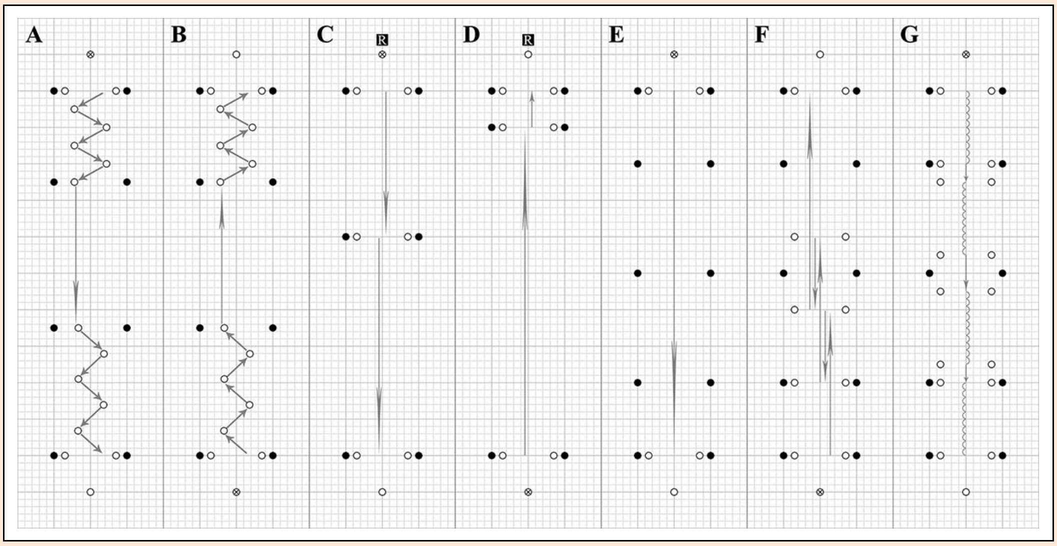

Figure 1. Overview of the validation protocol, involving seven different movements executed back and forth over a 60-m course of which the first and last 5 m are covered walking. A: sideways shuffling with five 60-degree and five 90-degree turns; B: diagonal jogging with five 90-degree and five 60-degree turns; C: 20 m maximal acceleration and 30 m gradual deceleration; D: 45 m gradual acceleration with 5 m maximal deceleration; E: 50 m backwards jogging; F: 90 m shuttle running with six 180-degree turns; G: four 10 m sideways skipping ladders while alternating side facing and total of 10 m walking in between. Black dots represent timing gates, white dots cornering poles or gates, crossed dots start points, black squares with "R" the radar gun and grey lines the movement direction.

ally simulated the activity previously observed during competitive football, both in style as well as the intensity of locomotion [see Table 1; (Bloomfield et al., 2007)]. The movements of the experimental trials were interspersed by short periods of static behaviour (5-10 s). These were included to enhance the ecologically validity of the protocol, as players are stationary for approximately 5% of playing time (Bloomfield et al., 2007). Each trial involved the continuous execution of the different movements and since some involved cornering or turns, a total distance of 500 m was covered per session (see Table 1). To ensure participants followed the planned course accurately, vertical pole gates and slalom poles were used which the participants had to cross and round as closely as possible.

Measurements

The GPS devices provided by the manufacturer (TT01, Tracktics GmbH, Hofheim, Germany; firmware version 1.7) collected positional data at a frequency of 5 Hz and triaxial accelerometer data at 200 Hz. Initially, the raw velocity data from the GPS-chip was computed onboard using two methods: positional differentiation and the Doppler-shift method. The final data describing distance, velocity and acceleration followed from the integration of input provided by all onboard components, such as the GPS-chip and accelerometer. These automated computations had been designed to continuously determine the most likely movement trajectory, depending on the quality of the available data.

The GPS tracker was designed to be worn centred on the lower abdomen, within a specifically designed belt below the elastic band of the shorts (see Figure 2A and 2B). The belt moves the tracker in a forward-tilted position, optimising antenna functionality (see Figure 2C). Each participant was assigned a personal device, which was used throughout the study in order to minimise inter-unit variability. The devices were activated in advance, to ensure a sufficient satellite fix, indicated by a LED light on the devices, prior to each trial.

Table 1. Distribution of distances covered for various styles of locomotion during seven types of movements.

Exercise	A	B	C	D	E	F	G	Total
Walking	20	20	10	10	5	5	5	75
Jogging		50		15	50	40		155
Running				25		25		50
Sprinting			20	5				25
Skipping							40	40
Shuffling	50							50
Other	10	10	30	5	5	30	15	105
Total	80	80	60	60	60	100	60	500

Distances are reported in m. Movements: A=sideways shuffling with five 60-degree and five 90-degree turns; B=diagonal jogging with five 90-degree and five 60-degree turns; C=20 m maximal acceleration; D=45 m gradual acceleration with maximal deceleration; E=50 m backwards jogging; F=shuttle running with six 180-degree turns; G=four 10 m sideways skipping ladders while alternating side facing.

The average number of satellites connected to the devices during the first trial was 13.3 ± 1.2 and for the second trial 13.5 ± 1.3. Furthermore, the average horizontal dilution of precision (HDOP), which describes the arrangement of the connected satellites across the sky, was 0.78 ± 0.05 and 0.75 ± 0.06 for the first and second trial, respectively. As it has been described that a connection to more than six satellites and HDOP values below 1 describe ideal conditions, the collected data was deemed suitable for analysis (Malone et al., 2017). As the GPS devices created encrypted data files, the time series of distance and velocity data were provided by the manufacturer, who was blinded to the testing protocol. These time series consisted of computed raw data, taking all input and metadata into account. No smoothing filters were applied at any time during the analyses within the current study. This data was then synchronised based on the time stamps of the criterion measures and the start of the GPS data was set for the first acceleration where a velocity >2 $m \cdot s^{-1}$ was reached after a 10 s period of static behaviour prior to the first section of the protocol (Hoppe et al., 2018).

Actual distance as well as average and peak velocity were included as criterion measures and recorded using a measuring tape, single-beam timing gates (TC PhotoGate, Brower Timing, Draper, USA), and a hand-held radar gun (ATS-II, Stalker Sport, Richardson, USA). The timing gates were placed along the course to measure average velocity over intervals ranging from 20 to 50 m (Earp and Newton, 2012; Haugen et al., 2014). Peak velocity was measured for six players during sections C and D (see Figure 1; (Beato et al., 2018).

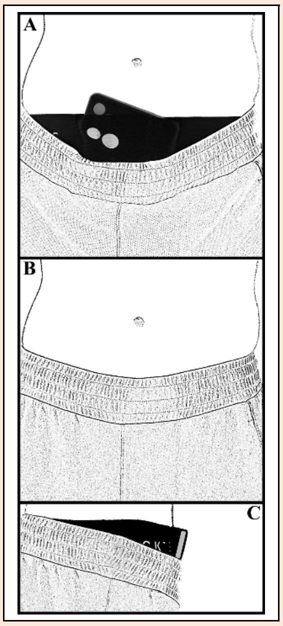

Figure 2. Abdominal positioning of the GPS device. The top image (A) shows the specifically designed belt wherein the GPS device is secured by sliding it in from the top. The middle image (B) shows the final wearing situation, where the belt and device are concealed and secured by the shorts of the player. The bottom image (C) shows the side view, where the device (depicted in grey) is tilted forward, and improving satellite reception.

Statistical analysis

Outcomes are displayed, where appropriately, as mean ± standard deviation (SD) and prior to analysis, all data was checked for normality using the Shapiro-Wilk test. Confidence limits (CL) were reported within square brackets. The standard error of the estimate (SEE) was calculated to determine the validity of the system for all different movements within the protocol (Petersen et al., 2009). The SEE is the standard deviation (reported along with 95% CL) of the %-difference between the GPS's time-motion data and criterion measures. The percentage difference was reported as the bias of the devices.

To determine the reliability of the GPS devices, both absolute errors (typical error; TE) and those expressed as a percentage (coefficient of variation; CV) were determined for distance and peak velocity (Jennings et al., 2010). The CV was rated qualitatively as *good* (<5%), *moderate* (5-10%), or *poor* (>10%) (Duthie et al., 2003; Scott et al., 2016). For the distance covered within the complete session, the true between-device SD was calculated using a linear mixed model. Within the model, trial was included as the fixed effect, whilst the device, device-by-trial interaction and the residual error were random effects.

Furthermore, as the timing gates only provide average velocity, the GPS data was averaged for the corresponding section of the course and separated into four different speed zones: walking (<7.2 $km \cdot h^{-1}$), jogging (7.2-14.4 $km \cdot h^{-1}$), high-speed running (14.4-21.6 $km \cdot h^{-1}$), and very high-speed running (>21.6 $km \cdot h^{-1}$) (Dwyer and Gabbett, 2012). The same zones were also used to describe the intensity of the protocol, by separating the recorded GPS data. Both instances and distances per speed zone were based on a minimum duration of 0.6 s above the threshold speeds. Pearson correlations (r) were calculated to determine the validity of the speed values derived from the GPS and criterion measure, as well as the relationship between the error and average speed measures. The magnitude of correlation was assessed using the following thresholds: <0.1, *trivial*; 0.1 to 0.3, *small*; 0.3 to 0.5, *moderate*; 0.5 to 0.7, *large*; 0.7 to 0.9, *very large*; and 0.9 to 1.0, *almost perfect* (Hopkins et al., 2009). All statistical methods were conducted using the statistical software package SPSS (Version 24; SPSS Inc., Chicago, IL, USA).

Results

The average distribution within the four speed zones throughout the protocol is presented in Table 2.

Table 2. Average distribution of distance and instances amongst four different speed zones within one session of the protocol.

Speed zone	Walking	Jogging	High-Speed Running	Very High-Speed Running
Distance (m)	144.0	240.1	87.5	28.4
Instances	27	30	7	2

Speed zones are separated into walking (<7.2km/h), jogging (7.2-14.4km/h), high-speed running (14.4-21.6km/h), and very high-speed running (>21.6km/h).

Validity

The precision of the GPS system during all movements of the validation protocol is presented in Table 3.

The SEE of the average velocity during the movements was found to be 5.4% [5.0; 5.9], with the average velocity measured by the timing gates and GPS indicating a significant and almost perfect correlation ($r = 0.98$ [0.97; 0.98], $p < 0.01$). The SEE for the speed zones was found to be 12.3% [10.5; 14.7] for walking, 9.3% [8.4; 10.4] for jogging, 6.0% [5.1; 7.3] for high-speed running, and 5.0% [3.4; 9.6] for very high-speed running. Here, a significant

Table 3. Validity and reliability of the GPS-system for each movement and the complete session including stationary phases.

Exercise	Distance Bias (%)	Distance SEE (% [CL])	Within-device distance TE (m [CL])	Within-device distance CV (% [CL])
Sideways	2.4	4.9 [3.8; 6.9]	3.2 [2.0; 7.1]	7.3 [4.7; 16.2]
Diagonal	-1.0	5.6 [4.2; 8.6]	3.6 [2.2; 8.7]	8.8 [5.5; 21.6]
Acceleration	-4.0	5.4 [4.3; 7.4]	2.8 [1.9; 5.3]	8.6 [5.8; 16.6]
Deceleration	0.0	4.3 [3.4; 6.0]	1.7 [1.2; 3.3]	4.9 [3.3; 9.4]
Backwards	-8.0	6.0 [4.6; 8.6]	3.4 [2.2; 7.6]	10.9 [7.0; 24.1]
Shuttle	2.5	3.4 [2.7; 4.6]	2.7 [1.9; 4.7]	4.6 [3.2; 8.1]
Skipping	-3.1	8.6 [6.6; 12.1]	5.4 [3.6; 11.0]	17.4 [11.5; 35.4]
Session	0.8	3.1 [2.2; 5.8]	6.7 [3.8; 25.1]	2.0 [1.2; 7.6]

SEE = standard error of the estimate; CL = 95% confidence limits; TE = typical error; CV = coefficient of variation.

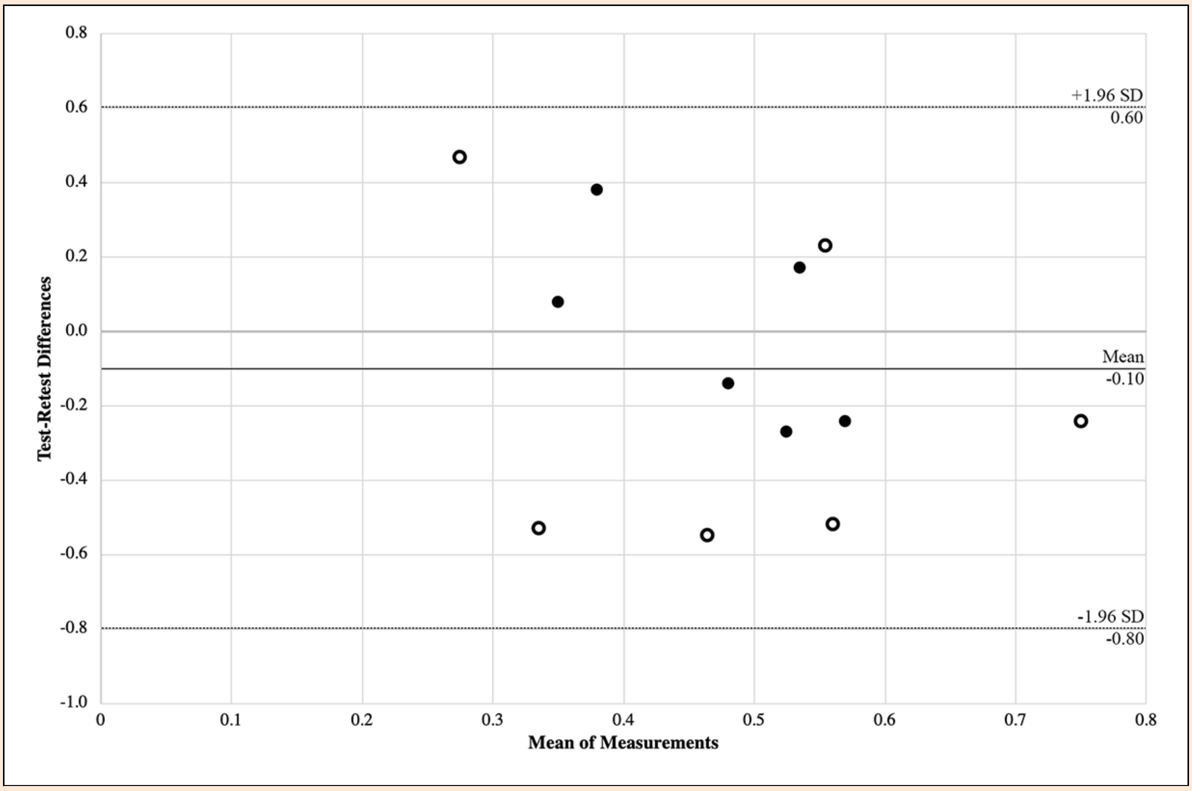

Figure 3. Bland-Altman plot for the test-retest error in peak velocity (in m•s^{-1}). Black dots represent acceleration runs and white dots deceleration runs.

and almost perfect correlation between SEE and the different ranges of velocity was found, describing a greater accuracy at higher speeds ($r = 0.96$ [0.88; 0.99]; $p = 0.04$). No significant correlation was found between the average velocity of the seven sections and the absolute error ($r = -0.29$ [-0.86; 0.59], $p = 0.26$).

The SEE of the peak speed was found to be 3.4% [2.6; 4.8], with no significant difference in the errors during movement C (maximal acceleration) and D (maximal deceleration; $p = 0.39$). Finally, a significant and very large correlation was found between peak speed measured by GPS and radar ($r = 0.79$ [0.57; 0.91], $p < 0.01$).

The system was found to both over- and underestimate criterion distance for different movements within the protocol, resulting in a small overestimation bias for the complete session (0.8%). A systematic underestimation of criterion velocity was recorded, with an underestimating bias of 7.2%.

Reliability

The highest variation, as can be seen in Table 3, was found during skipping movements involving 180-degree turns while moving sideways. Collectively, the total distance of the session indicated a good reliability (<5%), the reliability for five of the drills was moderate (5-10% CV), whilst backward and skipping movements indicated poor reliability (>10% CV). Furthermore, a TE of 0.25 m·s^{-1} [0.17; 0.46] was found for the test-retest error within peak speed, leading to a CV of 4.7% [3.2; 8.5] of the error between the trials. A Bland-Altman analysis also revealed agreement within the intra-unit differences (see Figure 3).

Mixed model

An observed 78.8% of the variance in total distance covered was due to the individual device. Since each player was assigned a specific device, the variance describes a players' variation in the execution of the trial. A further

20.8% of variance was explained by the interaction between the device and trial. Finally, merely 0.4% was explained by random errors. The true between-device SD, the intercept of the model, was found to be 2.9% for the complete session, which translates to 14.5 m over the 500 m course.

Discussion

The present study aimed to determine the accuracy of a newly designed low-cost GPS system. Time-motion data was gathered during a continuous protocol involving different movements specific to match-play in football and compared with two criterion measures (distance and velocity). The repeated execution of the protocol allowed for the calculation of the system's reliability. Overall, good accuracy was found for the distance covered during the complete protocol, with a SEE of 3.1% [2.2; 5.8] for validity and a CV of 2.0% [1.2; 7.6] for intra-unit reliability. For peak velocity, despite a systematic underestimation, similar results were found, where a SEE of 3.4% [2.6; 4.8] and a CV of 4.7% [3.2; 8.5] indicate appropriate validity and reliability. Errors and variance increased when movements deviated from a straight line, however remained within previously reported ranges of acceptability (<10%; (Scott et al., 2016). Furthermore, variations in change of direction ability may lead to differences between individuals executing the identical course, leading to the largest portion of variance. However, the overall true between-device SD was found acceptable (2.9%).

Interestingly, where previous studies have often found GPS systems to become less accurate with increasing velocities, the results of the current study indicated a small correlation between average velocity and the associated error (Coutts and Duffield, 2010; Jennings et al., 2010; Johnston et al., 2014). Relative to the velocity itself, the error was found to decrease with increasing average speeds over sections of the course. This effect was not due to changes of direction, which would decrease the average velocity, since no significant correlation between movement velocity and error was found. Additionally, the lowest accuracy was found for moving backwards in a straight line, whilst the greatest accuracy was found for shuttle running, which included four 180 degree turns. As such, high-speed movements, regardless of the direction of movement, may be confidently measured with the current GPS system. The significance of this finding lies with the notion that high-speed activities are considered highly important when analysing running behaviour in football (Carling et al., 2012; Faude et al., 2012).

Whilst the GPS devices used in the previously mentioned studies are designed to be worn in between the scapulae for improved satellite reception, the devices used in the present study are worn on the lower abdomen (see Figure 1). A placement close to the centre of mass (COM) has been proposed as more sensitive to changes in human gait in comparison to a “standard” placement on the upper back (Barrett et al., 2016). This may be explained by biomechanics, which defines positional tracking as the displacement of an individual's COM (Floor-Westerdijk et al., 2012). As such, the differences between the displacement and rotation of the COM and that of the shoulders whilst running are vastly different (Seay et al., 2011). With increasing velocities, arm swing becomes more pronounced and the greater displacement of the shoulders could increase noise for devices positioned in between the shoulder blades (Barrett et al., 2016). The same reasoning may explain the relatively limited accuracy of the current system when moving at lower velocities, sideways or backwards. When standing still, moving slowly, or not in a forward direction, movements of the abdomen and hips, unrelated to forward locomotion, might impact the accelerometer data. As introduced, this input plays a vital role in the final calculations of the time-motion data. Therefore, the positional data, otherwise relying on a relatively low sampling frequency of 5 Hz, may be greater affected. With increasing velocities, the movements around the COM will be predominately due to the locomotion itself, thereby possibly lowering the noise within the measurements and improving data accuracy. As such, this reduces the requirements for the hardware. For example, the current system features 5Hz GPS units in comparison with 15 Hz units in advanced systems used in elite environments. Consequently, the costs of the system can be minimised, increasing its availability across an array of competitive standards.

To further identify the effect of wearing positions, being in between the shoulder blades or on the lower abdomen, devices should be tested more intensively. However, this proves difficult with commercial GPS systems, since the devices are designed to be worn due to the manufacturer’s specifications. The input from the GPS-chip and accelerometer are converged in such a way, that the final time-motion data is most accurate when the tracker is worn in its intended location. Therefore, wearing a second device in an unintended position and comparing the results would be unrelated to the accuracy and specificity of the system. Comparisons of performance data collected by systems worn in different positions should also be avoided until further studies have been performed regarding the effect of device placement.

Because even when wearing two devices simultaneously close to their intended location, to calculate inter-unit variability (Rampinini et al., 2015), difficulties may arise. It has been found for different devices, that a certain distance should be present in between two devices, in order to exclude noise generated by the devices themselves (Hoppe et al., 2018). For the current system, it was deemed impossible to wear two devices on the designed location without affecting satellite reception, data or natural movements. It is because of these considerations, that the current study did not compare simultaneously worn units. However, the repeated use of the criterion measures provides an appropriate measure of intra-unit reliability (Beato et al., 2016). In order to allow for this intensified use of the criterion measures, the current study did not replicate previously performed protocols. Studies validating GPS systems for use in football have often performed a team sport running circuit (Bishop et al., 2001; Jennings et al., 2010). This protocol, however, only measures velocity over a short distance and thus, provides limited data on the variability of velocity.

The criterion measures for velocity should, however, be discussed, as both single-beam timing systems and hand-held radar were used in the present study to measure average and peak velocity, respectively. For such timing systems, larger errors have been found for small inter-gate distances (Earp and Newton, 2012). Therefore, the gates were placed at least 20 m apart and hand-held radar was used to measure peak velocity whilst accelerating and decelerating (Haugen and Buchheit, 2016). This meant different references were used, both with their specific errors of measurement. A possible solution would be the use of a high-resolution multi-camera motion analysis system, capable of accurately measuring instant velocity, regardless of the running direction (Duffield et al., 2010). Moreover, the use of such a reference system could provide the validation of more complex motions, like jumps or accelerations and decelerations. This would be advantageous as such short and explosive actions are deemed highly influential on player load (Harper and Kiely, 2018). Accurately providing such information would further increase the impact of any tracking system. However, although desirable, this validation technique is costly and not easily accessible. Nonetheless, it could be attempted by future studies to use such a high-speed motion analysis video system to preferably validate a variety of tracking systems (Hoppe et al., 2018; Linke et al., 2018). Moreover, this may also lead to direct comparisons of the effect of wearing position, like the current abdominal solution and that of previously validated GPS systems, worn between the scapulae.

Nevertheless, comprehensive data was collected through the protocol performed within the present study. The largest errors were found for sideways skipping and backwards jogging, which were found to be the least common types of locomotion during football matches (4.4% and 6.5% of time in motion, respectively; Bloomfield et al., 2007). Although better accuracy for all types of movements would be optimal, these errors do not seem to diminish the acceptable results for total distance and velocity.

Practical applications

Prior to the implementation of a tracking system into practice, the characteristics of the data they collect should be understood, regardless of the population of players (Buchheit et al., 2014). The GPS system in the current study was found to provide accurate and valid movement data. These findings are of particular importance due to the devices being designed to be more accessible and available for sub-elite teams; extending its applicability across a broader spectrum of coaches and practitioners. Potentially improving the scientific standard across all levels of the sport, for both performance as well as medical applications, allowing for better monitoring of athletes.

The accuracy of the current system, with a true-device SD of 2.9%, was deemed acceptable to indicate practically meaningful changes within the running load of players. For describing high-speed actions, considered highly important in football, the current system also shows to be a suitable tool, as acceptable accuracy was found for peak speed during sprinting and for average velocity within higher speed zones. Although no device-specific bias was found, the assignment of a specific device per player is advised, since no simultaneous tests were performed in the current study. Finally, practitioners should refrain from comparing training or match data from systems with different device placements, until further studies have been performed.

Conclusion

Taken together, the newly-designed GPS system used in the present study was shown to be sufficiently valid and reliable, and can thus be used with confidence for measuring running load in football. For the distance covered during the complete session, good validity, as well as intra-unit reliability was found. Peak velocity was found to be valid and reliable, since the systematic underestimation was determined unsubstantial. When changes in direction and style of locomotion were introduced, the accuracy decreased, however remained within previously published ranges of acceptability (<10%). Since the system relies on more affordable hardware components, it offers a lower financial burden which makes it available for sub-elite teams. This allows for a higher practical as well as scientific standard across multiple levels. Coaches and sport scientists may improve their monitoring and analyses, ultimately aiding the on-field performance. From a scientific standpoint, low-cost GPS devices like the currently validated systems may increase the numbers of studies performed, with greater sample sizes leading to a greater pool of data; providing novel insights into various aspects of football which elite teams may not be inclined to provide.

Acknowledgements

No sources of funding were used to assist in the preparation of this article. Emiel Schulze is supported by a ‘Science and Health in Football’ scholarship funded by the DAAD (German Academic Exchange Service). The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

References

Barrett, S., Midgley, A.W., Towlson, C., Garrett, A., Portas, M. and Lovell, R. (2016) Within-Match PlayerLoad Patterns During a Simulated Soccer Match: Potential Implications for Unit Positioning and Fatigue Management. *International Journal of Sports Physiology and Performance* **11,** 135-140.

Beato, M., Bartolini, D., Ghia, G. and Zamparo, P. (2016) Accuracy of a 10 Hz GPS Unit in Measuring Shuttle Velocity Performed at Different Speeds and Distances (5 - 20 M). *Journal of Human Kinetics* **54,** 15-22.

Beato, M., Coratella, G., Stiff, A. and Iacono, A.D. (2018) The Validity and Between-Unit Variability of GNSS Units (STATSports Apex 10 and 18 Hz) for Measuring Distance and Peak Speed in Team Sports. *Frontiers in Physiology* **9,** 1288.

Bishop, D., Spencer, M., Duffield, R. and Lawrence, S. (2001) The validity of a repeated sprint ability test. *Journal of Science and Medicine in Sport* **4,** 19-29.

Bloomfield, J., Polman, R. and O'Donoghue, P. (2007) Physical Demands of Different Positions in FA Premier League Soccer. *Journal of Sports Science and Medicine* **6,** 63-70.

Buchheit, M., Allen, A., Poon, T.K., Modonutti, M., Gregson, W. and Di Salvo, V. (2014) Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. *Journal of Sports Sciences* **32,** 1844-1857.

Carling, C., Le Gall, F. and Dupont, G. (2012) Analysis of repeated high-intensity running performance in professional soccer. *Journal of Sports Sciences* **30,** 325-336.
Coutts, A.J. and Duffield, R. (2010) Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science and Medicine in Sport* **13,** 133-135.
Duffield, R., Reid, M., Baker, J. and Spratford, W. (2010) Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport* **13,** 523-525.
Duthie, G., Pyne, D. and Hooper, S. (2003) The reliability of video based time motion analysis. *Journal of Human Movement Studies* **44,** 259-271.
Dwyer, D.B. and Gabbett, T.J. (2012) Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes. *Journal of Strength and Conditioning Research* **26,** 818-824.
Earp, J.E. and Newton, R.U. (2012) Advances in electronic timing systems: considerations for selecting an appropriate timing system. *Journal of Strength and Conditioning Research* **26,** 1245-1248.
Faude, O., Koch, T. and Meyer, T. (2012) Straight sprinting is the most frequent action in goal situations in professional football. *Journal of Sports Sciences* **30,** 625-631.
Floor-Westerdijk, M.J., Schepers, H.M., Veltink, P.H., van Asseldonk, E.H. and Buurke, J.H. (2012) Use of inertial sensors for ambulatory assessment of center-of-mass displacements during walking. *IEEE Transactions on Biomedical Engineering* **59,** 2080-2084.
Harper, D.J. and Kiely, J. (2018) Damaging nature of decelerations: Do we adequately prepare players? *BMJ Open Sport and Exercice Medicine* **4,** e000379.
Haugen, T. and Buchheit, M. (2016) Sprint Running Performance Monitoring: Methodological and Practical Considerations. *Sports Medicine* **46,** 641-656.
Haugen, T.A., Tonnessen, E., Svendsen, I.S. and Seiler, S. (2014) Sprint time differences between single- and dual-beam timing systems. *Journal of Strength and Conditioning Research* **28,** 2376-2379.
Hopkins, W.G., Marshall, S.W., Batterham, A.M. and Hanin, J. (2009) Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise* **41,** 3-13.
Hoppe, M.W., Baumgart, C., Polglaze, T. and Freiwald, J. (2018) Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports. *PLoS One* **13,** e0192708.
Jennings, D., Cormack, S., Coutts, A.J., Boyd, L. and Aughey, R.J. (2010) The validity and reliability of GPS units for measuring distance in team sport specific running patterns. *International Journal of Sports Physiology and Performance* **5,** 328-341.
Johnston, R.J., Watsford, M.L., Kelly, S.J., Pine, M.J. and Spurrs, R.W. (2014) Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *Journal of Strength and Conditioning Research* **28,** 1649-1655.
Linke, D., Link, D. and Lames, M. (2018) Validation of electronic performance and tracking systems EPTS under field conditions. *PLoS One* **13,** e0199519.
Malone, J.J., Lovell, R., Varley, M.C. and Coutts, A.J. (2017) Unpacking the Black Box: Applications and Considerations for Using GPS Devices in Sport. *International Journal of Sports Physiology and Performance* **12,** S218-S226.
Martin-Garcia, A., Gomez Diaz, A., Bradley, P.S., Morera, F. and Casamichana, D. (2018) Quantification of a Professional Football Team's External Load Using a Microcycle Structure. *Journal of Strength and Conditioning Research* **32,** 3511-3518.
Petersen, C., Pyne, D., Portus, M. and Dawson, B. (2009) Validity and reliability of GPS units to monitor cricket-specific movement patterns. *International Journal of Sports Physiology and Performance* **4,** 381-393.
Rampinini, E., Alberti, G., Fiorenza, M., Riggio, M., Sassi, R., Borges, T.O. and Coutts, A.J. (2015) Accuracy of GPS devices for measuring high-intensity running in field-based team sports. *International Journal of Sports Medicine* **36,** 49-53.
Scott, M.T., Scott, T.J. and Kelly, V.G. (2016) The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. *Journal of Strength and Conditioning Research* **30,** 1470-1490.
Seay, J.F., Van Emmerik, R.E. and Hamill, J. (2011) Low back pain status affects pelvis-trunk coordination and variability during walking and running. *Clinical Biomechanics* **26,** 572-578.
Torreno, N., Munguia-Izquierdo, D., Coutts, A., de Villarreal, E.S., Asian-Clemente, J. and Suarez-Arrones, L. (2016) Relationship Between External and Internal Loads of Professional Soccer Players During Full Matches in Official Games Using Global Positioning Systems and Heart-Rate Technology. *International Journal of Sports Physiology and Performance* **11,** 940-946.
Trewin, J.M., C., Varley, M.C. and Cronin, J. (2017) The influence of situational and environmental factors on match-running in soccer: a systematic review. *Science and Medicine in Football* **1,** 183-194.

Key points

- A newly designed and low-cost GPS system was found to provide reliable and valid data describing physical loading during football-specific movements.
- The system showed accurate measurements at higher running velocities, potentially due to different positioning of the devices on the body.
- The system relies on more affordable hardware components, offering a lower financial burden and making it available across a wider range of teams.

AUTHOR BIOGRAPHY

Emiel SCHULZE
Employment
PhD student at Saarland University
Degree
MSc
Research interests
Analysis of physical, tactical and technical performance in elite football
E-mail: e.schulze@uni-saarland.de

Ross JULIAN
Employment
PhD student at Saarland University, lecturer at the Institute of Neuromotor Behavior and Exercise at Münster University and visiting research fellow at the University of Gloucestershire
Degree
MSc
Research interests
Physiology of female football, human performance during sports and exercise
E-mail: julianr@uni-muenster.de

Sabrina SKORSKI
Employment
Researcher and lecturer at Institute of Sports and Preventive Medicine at Saarland University
Degree
PhD
Research interests
Recovery and fatigue, pacing in endurance sports, physiology of swimming, sleep and athletic performance;
E-mail: sabrina.forster@uni-saarland.de

✉ **Emiel Schulze**
Institute of Sports and Preventive Medicine; Saarland University, Campus B8.2, 66123 Saarbrücken, Germany

Science and Medicine in Football

Routledge
Taylor & Francis Group

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsmf20

Exploring Factors Related to Goal Scoring Opportunities in Professional Football

Emiel Schulze, Ross Julian & Tim Meyer

To cite this article: Emiel Schulze, Ross Julian & Tim Meyer (2022) Exploring Factors Related to Goal Scoring Opportunities in Professional Football, Science and Medicine in Football, 6:2, 181-188, DOI: 10.1080/24733938.2021.1931421

To link to this article: https://doi.org/10.1080/24733938.2021.1931421

Published online: 08 Jun 2021.

This publication was removed from the electronic version of the doctoral thesis for copyright purposes. DOI: https://doi.org/10.1080/24733938.2021.1931421.

Additional Research Output

Ross Julian, Sabrina Skorski, Anne Hecksteden, Christina Pfeifer, Paul S. Bradley, Emiel Schulze and Tim Meyer (2021). Menstrual cycle phase and elite female soccer match-play: influence on various physical performance outputs. *Science and Medicine in Football* **Volume 5 Issue 2**, Pages 97-104, https://doi.org/10.1080/24733938.2020.1802057

Information of the colloquium

Tag der Promotion: 21. April 2023

Dekan: Univ.-Prof. Dr. med. Michael D. Menger

Berichterstatter: Prof. Dr. med. Tim Meyer

Prof. Dr. Werner Helsen

Prof. Dr. Koen Lemmink