A complex, dynamic system called field hockey: Unravelling the complexities through performance analysis

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i. **Abstract**

The performance analysis of team sports involves the process of capturing, analysing, and visualising data to communicate insights and translate these into effective strategy. Actionable insights are gained by considering game strategy from both a simple and complex perspective. However, there is often a disconnect between research and practice resulting in ineffective communication of strategy. The aim of this thesis was to develop a practical performance analysis process for field hockey, that evaluated the holistic nature of sport performance and strategy by presenting several layers of critical game information. This thesis comprises five studies: a systematic review that identified and assessed performance analysis techniques in team invasion sports; a second systematic review that assessed the use of performance analysis in field hockey; two experimental studies that captured and analysed data on game styles and ball movement patterns among international field hockey teams; and finally, the development of a web-based application to illustrate and communicate the simple-to-complex layers of performance analysis.

A systematic review of the literature on all team invasion sports provided an overview of the evolution of the current best practice performance analysis techniques. Techniques included game actions, dynamic game actions, movement patterns, collective team behaviours, social network analysis, and game styles. Key factors to consider when designing a performance analysis system were game events in relation to time, space, opposition, and match context. However, these factors must be presented in simplified, practical profiles by analysing their interactions. The second systematic review, focused solely on performance analysis techniques and considerations in field hockey, was completed to identify gaps in the literature and the suitability of performance analysis techniques used in other sports to be employed in field hockey. Techniques identified were limited to outcome-focused approaches which reflects restricted resources and time available afforded to performance analysts in field hockey. The analytic method considered most effective to employ in field hockey based on the findings from Study 1 and Study 2 was game styles analysis. Game styles identify the consistent strategy implemented by a team through the clustering of similar dynamic game actions. This technique was deemed the most appropriate as game data are captured using basic equipment, and clustering algorithms eliminate the time needed for an analyst to detect patterns in the data manually.

The next two experimental studies were undertaken to quantify game styles using different perspectives. Game styles were identified by capturing and analysing in-game events, and ball movement patterns. Video footage of 131 games (n = 74 women, n = 57 men) from the 2019 Pro League international field hockey tournament were reviewed using a computerised notational analysis system. In-game events captured included game actions, stoppages, turnovers, and goal shots in relation to time, space, and the opposition. Variables were normalised by converting to percentages or ratios and divided into six categories of performance. A k-means cluster analysis was performed on each category, and two clusters were identified for each, reflecting the opposing game style types that could be used. Game style types included *strong* or *poor* for established and counter attack success, *high* or *low* for set piece occurrence, *dribbling* or *passing* for established and counter attack game actions, and *direct* or *possession* for tempo. The percentage of games each team implemented a particular game style was calculated, and a profile developed by identifying the game style types used consistently by a team. The influence of contextual factors on game style types was assessed using decision trees with opposition game style type, and other reference team game style categories having the greatest effect on performance. For example, for women, a team was 4 times more likely to be poor in established attack if the opposition were strong in counter attack; nearly twice as likely to pass in established attacks if they dribbled in counter attacks; and twice as likely to play direct if they were poor in counter attacks.

The second experimental study analysed ball movement patterns to identify how and where a team moved the ball to create goal scoring opportunities. A field was divided into 40 cells, and the start and end locations of ball movements were recorded, as well as play outcomes. Raw x, y data were converted to possession by calculating time for ball movements in each cell, entropy (a measure of variation/unpredictability in ball movements) was calculated by determining the likelihood of the ball moving from one cell to another, and progression rates calculated by considering the direction of ball movement between cells. The 40 cells were grouped into 7 attacking zones from deep in defence, to building an attack and creating a goal scoring opportunity. Collectively, these measures were used to provide practical insight into the strategies occurring in each phase of play. The influence of match context on movement patterns was assessed using linear mixed models, however few substantial effects were observed. Decision trees identified the most important variables determining play outcomes were possession in the circle (Goal Shot: 12.6% vs. Turnover: 1.2%), movement direct to goal from deep attack (Goal Shot: 41.8% vs. Turnover: 11%), and entropy in build attack (Goal Shot: 0.12 vs Turnover: 0.44) and build defence (Goal Shot: 0.10 vs. Turnover: 0.50).

A direct approach through the centre of the field was more likely to lead to a goal shot. However, limited goal scoring opportunities within a game indicates teams should be unpredictable to maintain possession until the opposition become unbalanced opening the opportunity to attack.

The trivial effect of match context on game styles and ball movement patterns reflects that there is more than one way to win a game, and teams need to develop strategies based on their strengths and ability to exploit the oppositions' weaknesses. These outcomes led to the final study; the development of a web-based application to visualise and communicate the analysis from the two experimental studies to showcase the similarities and differences, and strengths and weaknesses of individual teams. A Shiny application was developed in RStudio using the *shiny* R package, which produces an interactive web platform that is hosted and shared online. Each discrete step in the performance analysis process underpinned the development of the application. A central element is visualisations from holistic game style and ball movement profiles to technical-tactical indicators reflecting specific passages of play. The performance analysis process used in essence provides complexity to simple variables while simplifying the complex variables. The Shiny application forms a useful holistic and layered approach to understanding, developing and communicating strategy in field hockey and is freely accessible to performance analysts and coaches to implement findings in practice.

This thesis has assessed the practicality of performance analysis techniques in team invasion sports, and developed an evidence-based approach that can be used in field hockey based on readily-available resources. Novel approaches were utilised to develop game style and ball movement profiles to understand strategy by considering the effect of the opposition, time, and space. Visualisations accessed through a web-based application were used to connect the simple and complex variables surrounding strategy. The performance analysis process developed allows the complexity of strategy to be unravelled, facilitating performance analysts and coaches to better understand, develop and communicate strategy in practice.

ii. Publications

Published

Lord F, Pyne DB, Welvaert M, Mara JK. (2020) Methods of performance analysis in team invasion sports: A systematic review. *Journal of Sports Sciences* 38: 2338-2349.

Lord F, Pyne DB, Welvaert M, Mara JK. (2022) Field hockey from the performance analyst's perspective: A systematic review. *International Journal of Sports Science & Coaching* 17: 220-232.

Lord F, Pyne DB, Welvaert M, Mara JK. (2022) Identifying and analysing game styles and factors influencing a team's strategy in field hockey. *Journal of Sports Sciences* 40: 908-919.

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Conference Presentations

Title: The winning ways of women: Analysing strategy in field hockey using game styles
Details: 10-minute oral presentation, 8th IWG World Conference on Women & Sport, Auckland, New Zealand, 14-17 November 2022.

iii. List of Figures

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v. List of Supplementary Resources

vi. Preface

The formatting and reference styles utilised in Chapters 2 - 6 follows the journal specifications where these studies have been published. Chapters 2 and 4 are structured according to *Journal of Sports Sciences*, Chapter 3 according to *International Journal of Sports Science & Coaching*, Chapter 5 according to *Biology of Sport* and Chapter 6 according to *PLoS One*. Chapters 1 (Introduction), 7 (Translating Data into Strategy) and 8 (Discussion) are formatted slightly differently to the study chapters, but are still structured in a systematic manner throughout. Chapter, figure, table and supplementary resource titles are formatted consistently throughout the thesis being listed as chapter number followed by figure/table/resource number. Reference lists and supplementary resources are presented at the end of each chapter for convenience. The table below outlines the thesis structure identifying the study titles, types, and thesis chapters for reference.

Thesis Outline

Study	Title	Type	Chapter
1	Methods of performance analysis in team invasion sports: A systematic review	Systematic Review	2
2	Field hockey from the performance analyst's perspective: A systematic review	Systematic Review	3
3	Identifying and analysing game styles and factors influencing a team's strategy in field hockey	Experimental	4
4	Predicting the unpredictable: analysing the entropy and spatial distribution of ball movement patterns in field hockey	Experimental	5
5	Capture, Analyse, Visualise: an exemplar of performance analysis in practice in field hockey	Product Development	6

Chapter 1 - Introduction

Performance analysis is a growing area of sport science that allows objective information from matches to be captured and analysed so coaches can understand and develop effective attacking and defensive strategies and tactics. Strategies are plans that have been developed pre-game on how a team intends to attack and defend which they believe will provide them with the greatest chance of success (Grehaigne et al., 1999). Tactics are the plans developed in-game in reaction to the opposition's game plan and changing game situation (Grehaigne et al., 1999). Performance analysis methods have evolved with emerging technologies and perspectives allowing more informative data to be captured. However, the effective communication and translation of these data into strategy is still an area that can be improved. This thesis will explore the performance analysis process, its evolution and current trends, and provide an example of developing and implementing a practical performance analysis process in field hockey.

The role of a performance analyst is to capture, analyse, visualise and communicate information required to understand and develop strategy in team invasion sports (Wright et al., 2013). Performance analysts can collect data that relates to physical, technical, or game-based aspects of performance. However, the thesis will focus on the collection of game-based data as this was the type of data we could access. The objective of team invasion sports is to outscore the opponent, and consequently all team strategies revolve around a common aim of creating and defending goal scoring opportunities (Grehaigne et al., 1999; Hughes and Bartlett, 2002). However, how each team attempts to achieve this aim will be different due to the variety of strengths and weaknesses of the individual players within a team. Furthermore, team invasion sports are now acknowledged as dynamic, complex systems as the players interact with their team-mates and opposition in a constantly changing environment (Ribeiro et al., 2019; Ribeiro et al., 2017; Soltanzadeh and Mooney, 2016; Travassos et al., 2013). Therefore, a coach must also understand the effect of spatio-temporal variables and opposition interactions on actions and outcomes when assessing and developing a strategy. Although the aims of a strategy are simple, the processes involved to achieve them are often complex. Strategy can be manipulated by the team structures, actions used to move the ball, the attacking intent, and directness and predictability of ball movement. An analyst must capture and analyse the multitude of factors that can manipulate strategy, however which practical performance analysis methods are most effective to accomplish this remains unclear.

Performance analysts traditionally identified outcome-orientated variables that separated winning and losing teams (Hughes and Bartlett, 2002). Outscoring an opponent on these variables, labelled as key performance indicators, were suggested to lead to success. For example, key performance indicators in soccer included having greater game possession, goal shots, and converting more goal shots to goals (Lago-Penas et al., 2010; Lago-Penas et al., 2011). These outcome-oriented variables highlight key areas of the game to focus on and allow team performances to be compared in relation to a match result. However, these indicators do not explain how to create greater possession, goal shots or goals and therefore how to improve performance. This shortcoming limits the impact these results can have on developing strategies to be successful and their usefulness for a coach.

However, as technology improved, performance analysis techniques have also evolved due to the ability to capture a greater amount and more detailed data. The evolution from hand notation to computerised notational software and automated tracking systems has allowed process-oriented variables to be captured which analyse game events in relation to spatio-temporal variables and opposition interactions (Gudmundsson and Horton, 2017; O'Donoghue, 2006). The development of process-oriented techniques provides greater information on the context of game events which is more useful for developing strategies. For example, goal scoring opportunities are more likely to be created in field hockey by moving the ball down the sides of the field before transferring the ball to the top of the circle (Stockl and Morgan, 2013; Sunderland et al., 2006). The inclusion of spatial information in relation to game events is information that can be utilised by a coach, practised in training drills and adapted to suit the strengths of a team to implement during a game. Contemporary data capture technology has resulted in a substantial increase in data generation and availability which has presented analysts with a new challenge of translating large, complex data sets into effective insights into strategy. Understanding how to capture, analyse, visualise and communicate this form and amount of data needs to be investigated to provide practical guidelines to analysts in the field.

The main role of a performance analyst is interpreting and translating data into strategy for coaches to implement in practice. How this information is communicated is central to the development of the process to capture, analyse and visualise data underpinning the main focus of this thesis. An effective performance analysis process involves striking a balance between providing information in simple and practical profiles, but reflecting the complexities occurring within sport. Data aggregation techniques (such as factor analysis

which group variables (Fernandez-Navarro et al., 2016), or clustering algorithms which group observations (Lamb and Croft, 2016)) provide a method of summarising the complex variables into a reduced number of integrated data points without losing the level of detailed captured. An analyst is then able to communicate strategy using their experience and domain knowledge by understanding how and why the complex variables interact to reflect a game style in practice. Combining similar game actions or events into factors or clusters allows the key areas, and ways in which strategy can be manipulated, to be identified. This process produces game styles which are defined as the consistent strategy implemented by teams (Hewitt et al., 2016). Game styles relate processes to outcomes within different areas of the game giving practical insight into how a team intends to be successful. For example, game styles have been identified based on attack types in soccer. Teams were categorised according to whether they were moderately strong in established defence, stronger in transition moments, or stronger in established attack and set pieces (Gollan et al., 2018). Alternatively, game actions can be used to construct the game styles such as in rugby union, where a ball-carrying high-contact game style and a low-possession kicking game style were identified as winning strategies for different teams (Croft et al., 2015). A combination of inputs can also be used to provide a more holistic view on strategy. For example, attacking styles in soccer were identified based on possession directness, width of ball regains and progression, and the use of crosses (Fernadez-Navarro et al., 2016). Game styles analysis is a relatively new analytic method, and the process of capturing, analysing and visualising related data can be improved with further research.

Field hockey is a team invasion sport, where players use a carbon/fiberglass stick approximately reaching hip height to hit a cricket-sized plastic ball into the oppositions goal. Field hockey is played on a 91.4 m long and 55 m wide artificial turf field, consists of four 15 min quarters and each team may have no more than 11 players on the field at one time with no interchange limits (FIH Rules of Hockey 2022). A team typically consists of a goal keeper, 2 wide and 1 central defenders, a defensive midfielder and 3 attacking midfielders and 3 strikers. To win a game of hockey, a team must outscore the opposition, however a goal may only be scored in field hockey from within the circle (FIH Rules of Hockey 2022). The circle is a D shaped semi-circle, 15 m radius from the goal posts, positioned in the centre of the baseline. A goal may be scored from open play or from a penalty corner which is awarded due to an infringement in the circle by the defence. A penalty corner provides the attacking team with an opportunity to attempt a set routine against 5 opposition players giving them an advantage. Other unique stoppages include long corners and 16s; the ball is

played over the baseline by the defensive and attacking team respectively and play restarts from the 25m line in line with where the ball went out by the opposition team. Common infringements include the ball hitting a player's foot, a player using the reverse side of the stick or touching an opposition players' stick instead of the ball, lifting the ball into a player above the knee, obstructing an opposition player from reaching the ball and the ball being played out of bounds (FIH Rules of Hockey 2022). The rules have evolved over time including the removal of the offside rule and allowing players to dribble from a free hit scenario, instead of having to pass to a team mate, which has increased the speed and attacking play with the creation of greater goal scoring opportunities increasing the entertainment value for spectators.

Field hockey is played in over 90 countries across the world, however, performance analysis research is both limited in number and to more traditional approaches. Research has focused on identifying movement patterns to create goal scoring opportunities from open play (Sunderland et al., 2006; Stockl and Morgan, 2013) and penalty corners (Laird and Sutherland, 2003; Pineiro et al., 2007), the effect of rule changes (Tromp and Holmes, 2011) and specific game actions (Amjad et al., 2013; Ariff et al., 2015; Lythe and Kilding, 2013). International field hockey is limited by funding and publicity which restricts the resources and personnel available for performance analysis in practice. Teams may have one or two full time analysts working live during a game with basic equipment, a video camera and computerised notational analysis system. Consequently, the information captured in-game is restricted to basic game events. Major international tournaments such as the Olympics or World Cups, are generally played across a two-week period limiting the time for further analysis post-match during the tournament due to the quick turnaround between games. Professional leagues in other team invasion sports such as soccer, basketball or Australian Football are able to afford the costs to have external sports data companies such as Champion Data (https://www.championdata.com) or Stats Perform (https://www.statsperform.com/opta/) provide comprehensive game analysis. These companies produce large databases of game events, and ball and player tracking data which are available for not only teams but fans to access and researchers to analyse. The lack of access to readily available data, possibly unaffordable for field hockey leagues, may have limited the research productivity in field hockey which reflects the use of traditional approaches in practice (Laird and Sutherland, 2003; Sunderland et al., 2006). Research must echo the conditions in practice and provide innovative ways to provide greater insight into strategy with the resources available. Adapting the current performance analysis approach

during a game to be more specific to analysing strategy, as opposed to match outcomes, will provide more informative insight into whether a team is executing their game plan.

There is an opportunity to explore the way performance is captured and analysed, and translated from large, complex data sets into strategy in field hockey. Manipulating strategy can be divided into two areas, what a player does with the ball and how they move the ball around the field. However, strategy is also influenced by time, space and the opposition. For example, when a player has control of the ball and is assessing what to do next, their decisions and actions are influenced by their location on the field, the attack type and the pressure applied by the opposition. There is a need to assess strategy from two different perspectives, namely in-game events and ball movement patterns with a greater focus on the effect of the opposition and spatio-temporal variables respectively, to provide alternate and novel performance analysis methods. Different types of variables and forms of data captured, analysis methods and visualisation techniques can be assessed to identify which is the most practical and effective performance analysis method. Methods considered to be effective provide insight into how and why teams are successful and can be communicated in simple language, reflective of the way strategy is discussed in practice. Insights gained can be practiced and developed in training and implemented during a game to improve performance. The performance analysis process in field hockey can be adapted to provide contemporary insights into strategy with the traditional resources available.

While research has evolved to capture and analyse strategy in team invasion sports, there is limited research on data visualisation to effectively communicate insight into strategy. However, growing interest in the area has coincided with an increase in spatio-temporal data as the majority of research has been published in recent years and focused on visualising tracking data (Perin et al., 2018). Visualising spatial data allows individual and group movement patterns to be identified, and temporal visualisations can be used to highlight how variables change over time (Stein et al., 2017). For example, SoccerStories analyses corners kicks, goal shots and passing clusters using a variety of heat maps and line plots (Perin et al., 2013). TenniVis provides a Fish Grid and Pie Meter view on how the score line progressed through a match, utilising colour to highlight points and matches won and lost (Polk et al., 2014). Visualisations are the medium by which information is communicated so they need to be presented in a form that is simple to interpret and key trends can be easily identified by the audience. However, layers of detail can be uncovered with closer inspection by utilising different graphic aesthetics such as colour, shape, and size. The process of identifying game

styles takes steps to reduce the data to practical profiles. However, the production of visualisations should complement this process and yield a logical sequence of graphics that culminate in a clear coherent strategy. The progression of visualisations presented should allow a coach to understand a team's holistic game plan, identify what makes this team different, and the technical-tactical indicators that are the building blocks of a team's strategy. There is an opportunity to present a novel approach to performance analysis by linking the simple and complex layers of information through visualisations to communicate practical insight into strategy.

1.1 Aims

The aim of this thesis was to develop an evidence-based performance analysis process that provides practical insight into strategy by capturing, analysing, visualising, and communicating layers of simple and complex information. To achieve this thesis aim, five studies were undertaken consisting of the following objectives:

Study 1. Methods of performance analysis in team invasion sports: A systematic review

1. Describe the traditional and contemporary methods and techniques employed in performance analysis research in team invasion sports
2. Evaluate the practicality of identified performance analysis techniques
3. Provide recommendations on current best practice performance analysis techniques

Study 2. Field hockey from the performance analyst's perspective: A systematic review

1. Identify the performance analysis techniques utilised in field hockey
2. Evaluate the effectiveness and practicality of performance analysis methods currently employed in field hockey

Study 3. Identifying and analysing game styles and factors influencing a team's strategy in field hockey

1. Identify game styles of international field hockey teams
2. Assess the impact of contextual factors on international field hockey team's game styles

Study 4. Predicting the unpredictable: analysing the entropy and spatial distribution of ball movement patterns in field hockey

1. Analyse the entropy and spatial distribution of ball movement patterns in international field hockey
2. Identify common attacking ball movement patterns in international field hockey
3. Assess the impact of contextual factors on international field hockey team's ball movement patterns

Study 5. Capture, Analyse, Visualise: an exemplar of performance analysis in practice in field hockey

1. Outline a performance analysis process in field hockey to develop and communicate strategy
2. Develop a Shiny application in RStudio to illustrate how to communicate strategy

1.2 References

1. Amjad I, Hussain I and Asadullah M. (2013) Comparison between long corners and short corners in field hockey. *Rawal Medical Journal* 38: 428-431.
2. Ariff M, Norasrudin S, Rahmat A and Shariman I. (2015) Passing sequences towards field goals and penalty corners in men's field hockey. *Journal of Human Sport & Exercise* 10: S638-S647.
3. Croft H, Lamb P and Middlemas S. (2015) The application of self-organising maps to performance analysis data in rugby union. *International Journal of Performance Analysis in Sport* 15: 1037-1046.
4. Fernandez-Navarro J, Fradua L, Zubillaga A, Ford PR and McRobert AP. (2016) Attacking and defensive styles of play in soccer: analysis of Spanish and English elite teams. *Journal of Sports Sciences* 34: 2195-2204.
5. Gollan S, Ferrar K and Norton K. (2018) Characterising game styles in the English Premier League using the "moments of play" framework. *International Journal of Performance Analysis in Sport* 18: 998-1009.
6. Gréhaigne J-F, Godbout P and Bouthier D. (1999) The foundations of tactics and strategy in team sports. *Journal of Teaching in Physical Education* 18: 159-174.
7. Gudmundsson J and Horton M. (2017) Spatio-temporal analysis of team sports. *ACM Computing Surveys (CSUR)* 50: 1-34.
8. Hewitt A, Greenham G and Norton K. (2016) Game style in soccer: what is it and can we quantify it? *International Journal of Performance Analysis in Sport* 16: 355-372.
9. Hughes MD and Bartlett RM. (2002) The use of performance indicators in performance analysis. *Journal of Sports Sciences* 20: 739-754.
10. Lago-Penas C, Lago-Ballesteros J, Dellal A and Gomez M. (2010) Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of Sports Science and Medicine* 9: 288-293.
11. Lago-Penas C, Lago-Ballesteros J and Rey E. (2011) Differences in performance indicators between winning and losing teams in the UEFA Champions League. *Journal of Human Kinetics* 27: 137-148.
12. Laird P and Sutherland P. (2003) Penalty corners in field hockey: a guide to success. *International Journal of Performance Analysis in Sport* 3: 19-26.
13. Lamb P and Croft H. (2016) Visualizing rugby game styles using self-organizing maps. *IEEE Computer Graphics and Applications* 36: 11-15.

14. Lythe J and Kilding AE. (2013) The effect of substitution frequency on the physical and technical outputs of strikers during field hockey match play. *International Journal of Performance Analysis in Sport* 13: 848-859.
15. O'Donoghue P. (2006) The use of feedback videos in sport. *International Journal of Performance Analysis in Sport* 6: 1-14.
16. Perin C, Vulliment R and Fekete J-D. (2013) SoccerStories: a kick-off for visual soccer analysis. *IEEE Transactions on Visualization and Computer Graphics* 19: 2506-2515.
17. Perin C, Vuillemot R, Stolper CD, Stasko JT, Wood J and Carpendale S. (2018) State of the art of sports data visualization. *Computer Graphics Forum* 37: 663-668.
18. Piñeiro R, Molinuevo JS and Roman IR. (2007) Differences between international men's and women's teams in the strategic action of the penalty corner in field hockey. *International Journal of Performance Analysis in Sport* 7: 67-83.
19. Polk T, Yang J, Hu Y and Zhao Y. (2014) TenniVis: visualization for tennis match analysis. *IEEE Transactions on Visualization and Computer Graphics* 20: 2339-2348.
20. Ribeiro J, Davids K, Araújo D, Silva P, Ramos J, Lopes R and Garganta J. (2019) The role of hypernetworks as a multilevel methodology for modelling and understanding dynamics of team sports performance. *Sports Medicine* 49: 1337-1344.
21. Ribeiro J, Silva P, Duarte R, Davids K and Garganta J. (2017) Team sports performance analysed through the lens of social network theory: implications for research and practice. *Sports Medicine* 47: 1689-1696.
22. Soltanzadeh S and Mooney M. (2016) Systems thinking and team performance analysis. *International Sport Coaching Journal* 3: 184-191.
23. Stein M, Janetzko H, Seebacher D, Jager D, Nagel M, Holsch J, Kosub S, Schrek T, Keim DA and Grossniklaus M. (2017) How to make sense of team sport data: from acquisition to data modeling and research aspects. *Data* 2: 1-23.
24. Stöckl M and Morgan S. (2013) Visualization and analysis of spatial characteristics of attacks in field hockey. *International Journal of Performance Analysis in Sport* 13: 160-178.
25. Sunderland C, Bussell C, Atkinson G, Alltree R and Kates M. (2006) Patterns of play and goals scored in international standard women's field-hockey. *International Journal of Performance Analysis in Sport* 6: 13-29.
26. Travassos B, Davids K, Araujo D and Esteves PT. (2013) Performance analysis in team sports: advances from an ecological dynamics approach. *International Journal of Performance Analysis in Sport* 13: 83-95.

27. Tromp M and Holmes L. (2011) The effect of free-hit rule changes on match variables and patterns of play in international standard women's field hockey. *International Journal of Performance Analysis in Sport* 11: 376-391.
28. Wright C, Atkins S, Jones B and Todd J. (2013) The role of performance analysts within the coaching process: Performance Analysts Survey 'The role of performance analysts in elite football club settings'. *International Journal of Performance Analysis in Sport* 13: 240-261.

Declaration of Co-Authorship for Thesis Chapter 2

DECLARATION BY CANDIDATE

In the case of Chapter 2 the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Study design, analysis and interpretation, manuscript preparation	80

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Dr Jocelyn Mara	Design, analysis, editing	No
Prof David Pyne	Design, analysis, editing	No
Dr Marijke Welvaert	Design, analysis, editing	No

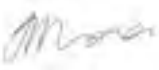
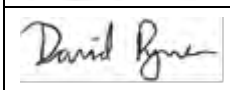
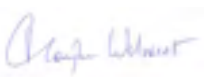
19/01/22

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: Research Institute for Sport and Exercise, University of Canberra

Signatures	Date
	28/01/22
	28/01/22
	28/01/22

Chapter 2 - Methods of performance analysis in team invasion sports: A systematic review

Lord F, Pyne DB, Welvaert M, Mara JK. (2020) Methods of performance analysis in team invasion sports: A systematic review. *Journal of Sports Sciences* 38: 2338-2349.

Abstract

The objective of this review was to systematically describe the traditional and contemporary data capture and analytic methods employed in performance analysis research in team invasion sports, evaluate the practicality of these methods, and formulate practical recommendations on methods for analysing tactics and strategies in team invasion sports. A systematic search of the databases SPORTDiscus, Web of Science, Scopus, MEDLINE and PubMed was performed. Key words addressed performance analysis methods and team invasion sports, with all other disciplines of sport science excluded. A total of 537 articles were included in the review and six main themes of research identified. Themes included game actions, dynamic game actions, movement patterns, collective team behaviours, social network analysis and game styles. Performance analysis research has predominantly focused on identifying key performance indicators related to success by analysing differences in game actions between successful and less successful teams. However, these measures are outcome-focused and only provide limited insight into winning team's strategy. Team invasion sports are now viewed as dynamic, complex systems with opposing teams as interacting parts. Strategies and tactics should be analysed using a holistic process-orientated approach by recording dynamic actions, collective team behaviours and passing networks, and viewing them in game styles.

Key words: game actions, movement patterns, collective team behaviours, social network analysis, game styles

2.1 Introduction

Team invasion sports are ball games played by two opposing yet interacting teams. These sports are characterised by the objective of invading the opponent's territory to score goals while simultaneously attempting to prevent the opposition scoring (Grehaigne et al., 1999; Hughes & Bartlett, 2002). Different types of team invasion games include sports where the ball is thrown into a net such as basketball or netball, struck with the foot or a stick into a goal such as soccer, Australian Football or field hockey, or where the ball is carried across a line such as American Football, rugby league or rugby union (Grehaigne et al., 1999; Lamas et al., 2014). While the point scoring methods are different between each type of sport, there are common phases of play in all team invasion sports. In attack, teams must maintain possession of the ball, progress the ball towards the oppositions defensive zone and attempt to move the ball into the target area (Grehaigne et al., 1999; Lamas et al., 2014). Concurrently, the opposition defends by slowing or preventing the movement of the ball towards their defensive zone and protecting their goal, basket or try line while also trying to regain possession of the ball (Grehaigne et al., 1999; Lamas et al., 2014). A team will develop strategies on how they wish to execute each stage of play that exudes their strengths and exploits the opposition's weaknesses (Grehaigne et al., 1999). Generally, offensive strategies aim to create an imbalance in the defence through a numerical advantage (Vilar et al., 2013), generating space by increasing the surface area of the team (Alexander, Spencer, Mara et al., 2019) or playing unpredictably (Hobbs et al., 2018). On the other hand, the defence attempt to hinder the offence by protecting the most critical areas of the field by applying zonal defensive pressure, defenders guarding a certain area on the field, or direct marking of an individual opposition player (Vilar et al., 2013).

Performance analysis techniques allow coaches and team support staff to gather objective measurements of performance from matches to understand and devise effective attacking and defensive strategies and tactics. Strategies are the game plans devised ahead of time on how a team intends to organise themselves in attack and defence to create goal scoring opportunities and prevent the opposition doing the same (Grehaigne et al., 1999). Whereas tactics are the game plans developed in game in response to the opposition's game plan and the constantly changing match conditions (Grehaigne et al., 1999). The performance analyst's role is to capture performance, analyse the data for key performance indicators related to success, and present this information in a simple and concise way for the coach to implement in practice (Wright et al., 2013). Information collected can provide live (real-time) insights into tactics and match performance, and allows feedback to be given on why a match result occurred by

identifying areas a team performed well and those they can improve on (Wright et al., 2013). The accumulation of data from multiple games allows patterns to be detected that can be used to prepare strategies for upcoming games based on the expected opposition game strategies. Data recorded by performance analysts have traditionally been outcome-focused variables such as percentage of possession, number of goal shots, percentage of tackles made out of tackles attempted or number of passes made (Hughes & Bartlett, 2002). However, for a team to improve they must understand the process involved to reach an outcome, so there has been a need in both research and practice to employ more practical methods of performance analysis (McGarry, 2009). Consequently, the perspective of team invasion sports has evolved, and researchers now view team invasion sports as a dynamic, complex system with the teams as interacting parts (McGarry, 2009; McGarry et al., 2002; Reed & Hughes, 2006; Travassos et al., 2013). A complex system is defined as an open system with multiple interacting components, each interaction is short ranged and influenced by the history of the system, consequently the system has no equilibrium (Salmon & McLean, 2020). Two teams are only in equilibrium before the first ball movement of the game as one team has not yet attacked to force the opposition to counteract their play. These developments have shifted the focus of key variables collected and analysed from outcome-orientated to process-orientated by incorporating spatio-temporal measures and player-opponent interactions (McGarry, 2009; McGarry et al., 2002; Reed & Hughes, 2006; Travassos et al., 2013). This reflects a holistic view on team invasion sports by encompassing all aspects that can affect game action outcomes and performance.

Advancements in data capture technology have underpinned the development of performance analysis methods (Liebermann et al., 2002). Early performance analysis work was captured live using hand notation and pen and paper, dating back to one of the pioneers of performance analysis Charles Reep and his annotation of passes and goal shots in soccer (Reep & Benjamin, 1968). This approach limited the data that could be collected to basic game actions or match events. Computerised video analysis software was then developed in the 1990s allowing synchronisation of video and notated match events to provide visual feedback (O'Donoghue, 2006). Retrospective analysis could also be undertaken to capture additional details post-match (O'Donoghue, 2006). More recently, the innovation of semi-automated tracking systems and global and local positioning systems have allowed player movements to be tracked in real time on the playing surface. This technology can be used in conjunction with notated match events allowing greater emphasis to be placed on spatio-temporal measures (Liebermann et al., 2002). The evolution of performance analysis methods

has resulted in a substantial increase in data generation and availability. However, this development has presented analysts with a new challenge of managing, analysing and translating this data into useful information. Further refinement of performance analysis methodologies, technologies, and means of effective translation into practical outcomes are needed to close this gap.

Performance analysis is a growing field and constantly evolving. There is a need to document the evolution of performance analysis to understand historical learnings, and identify current best practice methods and future directions in techniques and analytical approaches. This will provide performance analysts with a comprehensive review on the practicality of each method so they can implement appropriate techniques in the field and gain valuable insights into strategy. The aims of this systematic review were to describe the traditional and contemporary data capture and analytic methods employed in performance analysis research in team invasion sports, evaluate the practicality of these methods, and formulate practical recommendations on methods for analysing tactics and strategies in team invasion sports.

2.2 Methods

2.2.1 Design

A systematic review was conducted on performance analysis techniques in team invasion sports according to PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses). The search was completed on the 13 March 2019. Electronic databases used were SPORTDiscus, Web of Science, Scopus, MEDLINE and PubMed to search for relevant publications from the earliest publication in December 1997 to March 2019. A group of key words was selected based on the objectives of the study; “performance analysis”, “notational analysis”, “match analysis”, “game analysis”, “tactical analysis”, “patterns of play”, “game styles”, “performance indicators”, “dynamic systems”, “systems analysis”, “sports analytics”, “performance analytics”, and “team behaviour”. A second group of key words was developed to restrict the context of the articles; “team sport”, “invasion games”, “field hockey”, “soccer”, “football”, “rugby”, “basketball”, “netball”, “handball”, and “water polo”. Both groups of words were joined with the Boolean search term OR and connected through AND. Additionally a third group of words on themes that were to be excluded were joined using NOT; “injury”, “injury prevention”, “recovery”, “physical demands”, “match demands”, “loading”, “match load”, “technique”, “biomechanics”, “running”, “conditioning”, “fitness”, “physiology”, and “psychology”.

2.2.2 Inclusion and Exclusion Criteria

Two independent reviewers (FL and JM) separately assessed the resulting publications to determine their eligibility in the review. The inclusion criteria for the studies were: (1) analysis of data related to the evaluation of technical indicators, tactical movement patterns or strategies was presented; (2) participants were amateur or professional adult male or female athletes; (3) the sports studied were team invasion sports; (4) from a scientific journal. Articles were excluded if: (1) the participants were children (15 years or under); (2) individual or non-invasive team sports were studied; (3) match outcome, goals statistics or skill involvements were reported without reference to a tactical or strategic method; (4) contained themes relating to medicine, health, injuries, injury prevention, biomechanical, physical, psychological or teaching; (5) only described a theoretical model or analysed the reliability or validity of a performance analysis tool without applying it to a practical data set; (6) were from conference abstracts or systematic reviews; and/or (7) articles in other languages not providing an English abstract with sufficient information on methods and variables examined. If an article included both features of the inclusion and exclusion criteria, results are only reported for the relevant features. Where there was a disagreement on the inclusion of articles between the two independent reviewers, then the final decision was left to the senior author (JM) given greater experience on the subject matter.

2.2.3 Management and Selection of Studies

The initial database search returned 2153 articles. Duplicate articles were removed resulting in 1197 article titles and abstracts to be screened for relevance. A further 451 articles were excluded following this process. The remaining 746 full articles were examined, and another 209 articles were omitted for not meeting the inclusion criteria. The final sample consisted of 537 articles for systematic review. The screening process is shown in Figure 2.1.

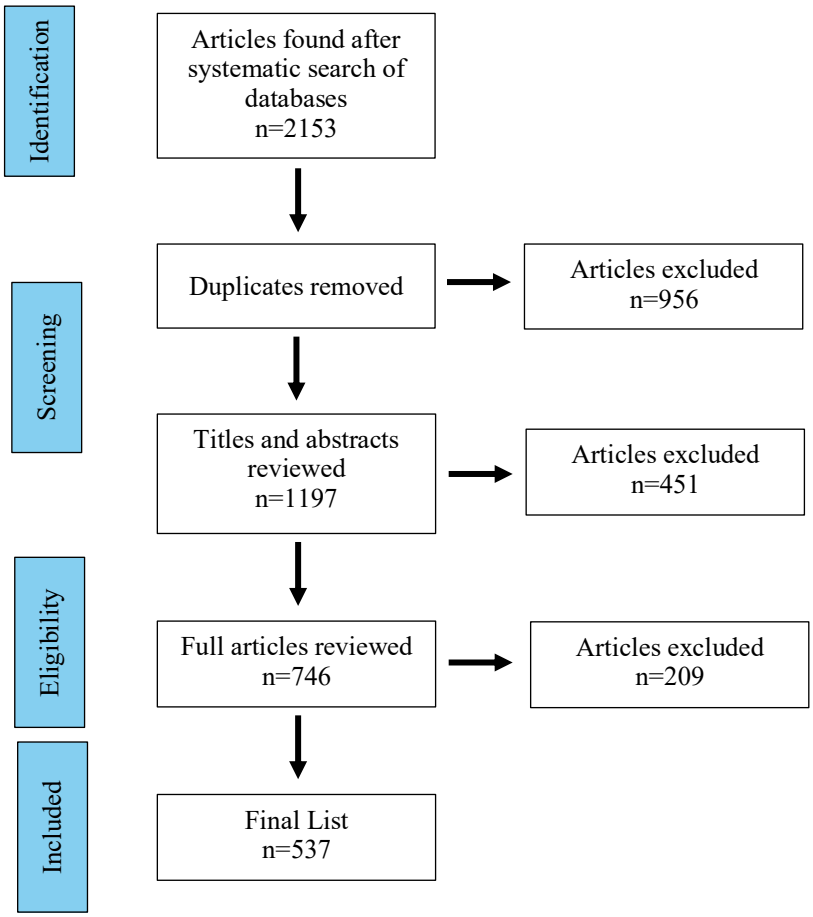


Figure 2.1 Screening process for selecting performance analysis studies in relation to themes and analytical methods

Results are organised by the main themes identified in the articles. These themes are defined to reflect the type of variables captured (outcome-orientated or process-oriented) and the analytic methods used to analyse and interpret the data. The statistical analysis methods and mediating or outcome variables used to analyse the data are listed in relation to each theme. The statistical analysis methods include: (1) descriptive statistics such mean, standard deviation, median or range, (2) inferential statistics reflecting methods testing a null hypothesis such as T-tests, ANOVA and correlation analysis indicating significant differences or associations within and between variables, (3) prediction models highlighting the probability or odds ratio of a variable contributing to success and (4) other methods such as data reducing methods (neural networks, factor analyses) or entropy calculations reflecting alternate approaches to analysing data. For the purpose of this review, traditional performance analysis methods reflect outcome-orientated approaches reporting team actions and match outcomes. Contemporary performance analysis methods encompass those

techniques reflecting a dynamic, complex system by using a process-orientated approach, reporting processes in relation to outcomes. One main theme was identified per article although an article may contain more than one type of statistical analysis method and mediating or outcome variables. The number of articles per category is presented in parentheses. Finally, recommendations are provided on performance analysis methods providing a practical approach to analysing strategic performance in team invasion sports. Practicality is evaluated on the ability to provide insight from a dynamic, complex system to reflect a process-orientated rather than outcome-orientated approach to understanding team strategy, as such the insight can be translated to inform training practices and the development of game strategies (McGarry, 2009; McGarry et al., 2002; Reed & Hughes, 2006; Travassos et al., 2013).

2.3 Results

2.3.1 The evolution of performance analysis techniques over time

Articles are indexed per sport in Supplementary Resource 2.1 based on the data capture theme of research and statistical analysis method employed. After reviewing the 537 articles, we identified a substantial increase in performance analysis research published over the last decade with nearly 90% of articles published after 2010. Six main themes of research were identified from the systematic review and are defined as:

1. Game Actions: any discrete technical action or game event, recorded per team as a frequency or percentage per game. For example, goals, shots at goal, passes, tackles, rebounds, corner kicks, or penalties (Hughes & Bartlett, 2002). Variables are recorded using hand or computerised notational analysis. Using inferential statistics, variables that were significantly different between successful and less successful teams were considered key performance indicators.
2. Dynamic Game Actions: technical actions that include the spatial locations on the field, speed of play or opposition interaction (Travassos et al., 2013), recorded as frequencies or percentages per game. Actions may be recorded per team or per individual player or position (James et al., 2005). For example, possession per area on field, controlled versus counter attacks, or level of defensive pressure during attempted goal shots. Variables are recorded using hand or computerised notational analysis. Using inferential statistics, variables that were significantly different between successful and less successful teams were considered key performance indicators.

3. Movement Patterns: a sequence of offensive or defensive play from when a team gains possession to the outcome of that possession. Patterns may occur during general play or during specific events or set plays such as corner kicks in soccer (Casal et al., 2015), pick and rolls in basketball (Marmarinos et al., 2016), ruck movements in rugby union (Kraak & Welman, 2014) or penalty corner routines in field hockey (Laird & Sutherland, 2003). Variables recorded as frequencies, included starting and end location zones, technical actions performed during the possession, speed of play, number of players involved, and type of outcome (Costa et al., 2017; Diana et al., 2017; Mara et al., 2012; Sunderland et al., 2006). Variables are recorded using hand or computerised notational analysis and inferential statistics were employed to compare the likelihood of success or failure of each pattern.
4. Collective Team Behaviours: how a team is structured or positioned across the field and in relation to the opposition. Measures included a team's length, width, centroid or surface area (Alexander, Spencer, Mara et al., 2019; Clemente et al., 2013; Clemente, Couceiro, Martins, Mendes et al., 2014). Variables are collected via tracking devices such as a global or local positioning system or semi-automated tracking system.
5. Social Network Analysis: team passing networks, frequency of passes between players are recorded using notational analysis and processed in an adjacency matrix. Measures included clustering coefficients, indegree centrality, outdegree centrality, closeness centrality and betweenness centrality which reflect the key distributors, receivers and linking players in a team (Clemente, Couceiro, Martins, Mendes et al., 2014; Clemente et al., 2015; McLean et al., 2018).
6. Game Styles: frequencies of game actions recorded using notational analysis, incorporating speed of play and spatial variables, are recorded and clustered into common styles of playing a game to reflect the attacking and defensive strategies used consistently by a team (Hewitt et al., 2016). Clustering of data can occur via factor analysis or neural networks.

The number of articles per sport for each theme identified is presented in Figure 2.2. The majority of performance analysis research has investigated soccer followed by basketball, rugby union and handball.

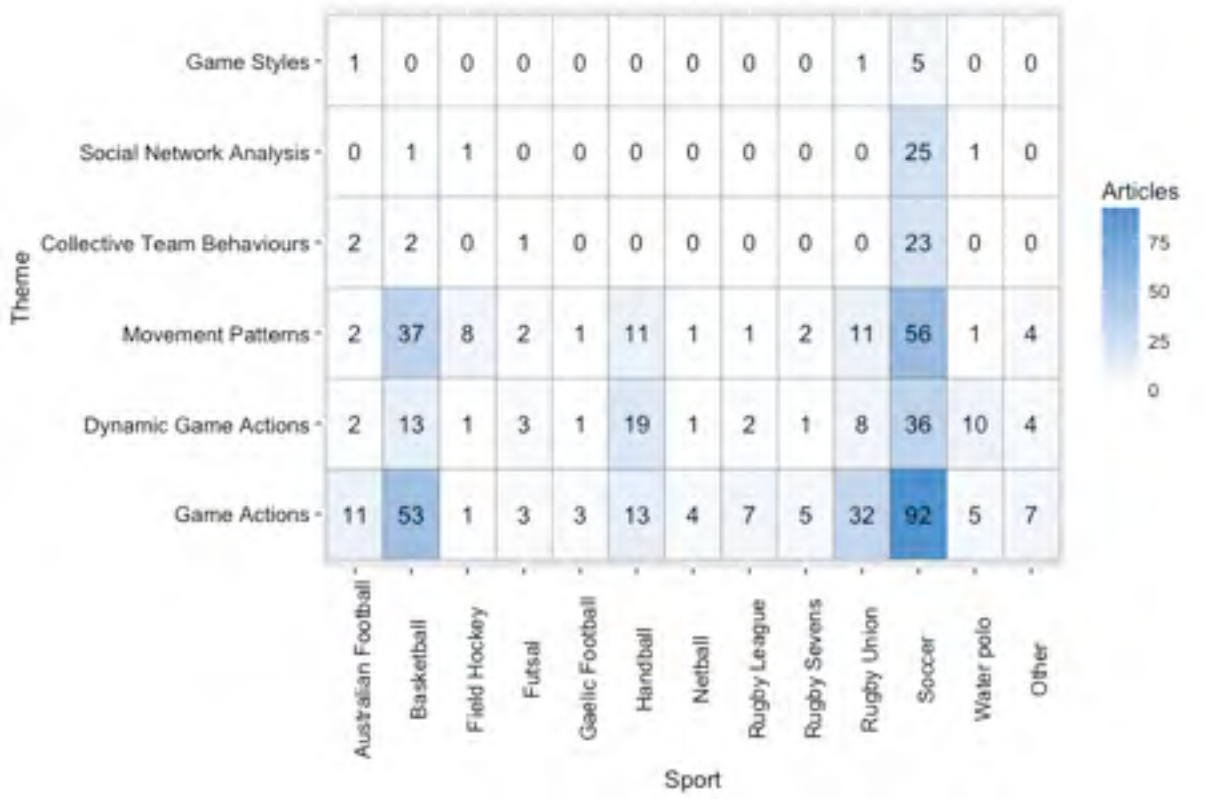


Figure 2.2 Number of performance analysis articles published per sport on each research theme

The number of published studies has increased substantially since 2010 (Figure 2.3). The most published area of research are game actions contributing to nearly 50% of articles in each five-year time period. Themes of dynamic game actions and movement patterns emerged around 2006 and research into these areas has continued to increase over the years. Interest into collective team behaviours and social network analysis began around 2011, although interest in collective team behaviours has reduced slightly while social network analysis has continued to rise. Game styles was the newest theme to emerge in 2016 highlighting the limited work in this area.

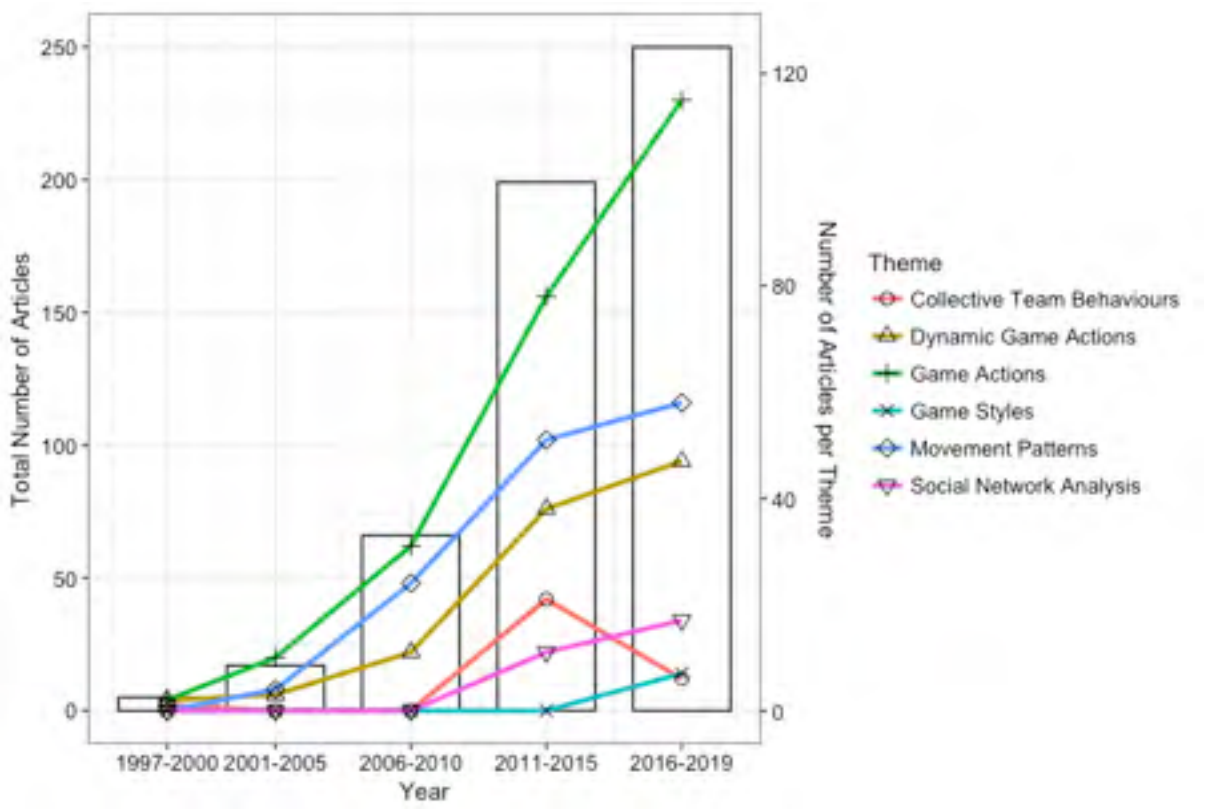


Figure 2.3 Number of articles per research theme (lines) and total number of performance analysis articles (columns) published per 5-year period

The majority of studies employed an inferential analysis to identify differences between successful and less successful performance (Figure 2.4). However, in the last 10 years there has been an increased number of prediction or modelling studies to characterise the effect of a variable on the likelihood of success. There has also been an increase in other data analysis methods such as neural networks (Dutt-Mazumder et al., 2011; Grunz et al., 2012), factor analyses (Fernandez-Navarro et al., 2016) and entropy (Hobbs et al., 2018). These methods are more suited to analysing data as a dynamic system and provide alternate ways of viewing a data set which may provide new insights into the variables analysed.

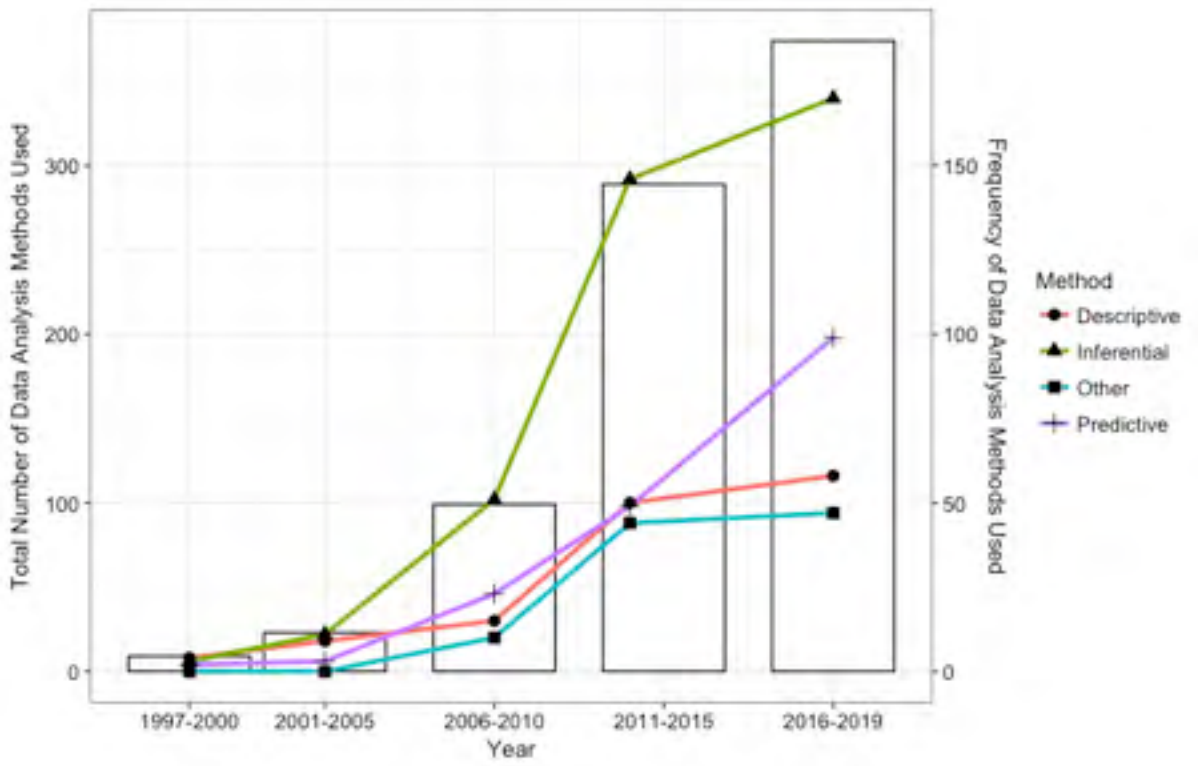


Figure 2.4 Frequency of data analysis methods used (lines) and total number of data analysis methods (columns) used per 5-year period

2.3.2 Game Actions

The theme of game actions was identified in 236 articles. Data analysis methods used for game actions included inferential statistics (n=166 articles), prediction (n=98), descriptive statistics (n=56), neural network (n=22), factor analysis (n=7), non-metric multidimensional scaling (n=5), norms (n=2), entropy (n=1) and recurrence plot (n=1). Variables analysed in conjunction with game actions include match outcome (n=75), team rank (n=28), match location (n=25), score difference (n=21), time period in game (n=16), teams (n=13), stage of tournament (n=12), playing season (n=11), tournament (n=11), individual characteristics (n=9), quality of opposition (n=8), league/division (n=7), game factors (n=6), match status (n=6), gender (n=5), rule change (n=5), action success (n=3), playing position (n=3) and match phase (n=1). Game actions were also used to predict match outcome (n=54), game actions (n=22), team rank (n=10), score difference (n=5), player/position (n=3), tournament (n=3), league/division (n=1), match location (n=1), playing season (n=1), score difference (n=1) and stage of tournament (n=1).

2.3.3 Dynamic Game Actions

A total of 101 articles were identified on the theme of dynamic game actions. Data analysis methods included inferential statistics (n=79), prediction (n=37), descriptive statistics (n=24), entropy (n=4), heat maps (n=3), neural network (n=3), factor analysis (n=3) and stochastic multicriteria acceptability analysis (n=1). Dynamic game actions were analysed in relation to action success (n=26), match outcome (n=21), time period in game (n=11), stage of tournament (n=9), match location (n=7), teams (n=7), playing season (n=6), score difference (n=5), team rank (n=5), individual characteristics (n=4), game factors (n=3), match status (n=2), playing position (n=2), possession success (n=2), tournament (n=2), league/division (n=1), match phase (n=1) and rule change (n=1). Dynamic game actions were also used to predict game actions (n=14), match outcome (n=12), player/position (n=3), score difference (n=3), playing season (n=2), team rank (n=1) and team identity (n=1).

2.3.4 Movement Patterns

Movement patterns was the theme of research in 137 articles. Data analysis methods included inferential statistics (n=103), prediction (n=38), descriptive statistics (n=33), neural network (n=7), polar coordinate analysis (n=3), entropy (n=2), heat maps (n=2), continuous triangular methods (n=1), data envelopment analysis (n=1) and ISOPAR method (n=1). Variables analysed in relation to movement patterns included action success (n=35), possession success (n=30), time period in game (n=15), match status (n=14), match outcome (n=11), match location (n=9), teams (n=8), playing position (n=7), team rank (n=7), league/division (n=5), playing season (n=4), stage of tournament (n=4), tournament (n=4), gender (n=3), quality of opposition (n=3), individual characteristics (n=2), score difference (n=2), match phase (n=1), rule change (n=1) and schedule/time in season (n=1). Movement patterns were used to predict game actions (n=36), match outcome (n=2) and team identity (n=1).

2.3.5 Collective Team Behaviours

A total of 28 articles were identified that analysed collective team behaviours. Methods of data analysis include inferential statistics (n=16), descriptive statistics (n=5), entropy (n=7), Voronoi diagram (n=3), heat maps (n=2), relative phase (n=2), factor analysis (n=1), neural network (n=1), network map (n=1) and prediction (n=1). Mediating or outcome variables on collective team behaviours include match phase (n=5), spatial variables (n=3), time period in game (n=3), match location (n=2), gender (n=1), league/division (n=1), match outcome (n=1), schedule/time in season (n=1), tactical line up (n=1) and teams (n=1). Team identity (n=1) was the only model predicted from collective team behaviours.

2.3.6 Social Network Analysis

Social network analysis was the theme of research in 28 articles. Data analysis methods used were inferential statistics (n=15), descriptive statistics (n=14), network map (n=11) and prediction (n=1). Social network analysis was investigated in relation to playing position (n=10), match outcome (n=5), stage of tournament (n=5), individual characteristics (n=2), tactical line up (n=2), time period in game (n=2), spatial variables (n=2), game factors (n=1), league/division (n=1), match location (n=1), match status (n=1), possession success (n=1), schedule/time in season (n=1), team rank (n=1) and tournament (n=1). Social network analysis was also used to predict game actions (n=1).

2.3.7 Game Styles

A total of 7 articles were identified investigating game styles. Methods of analysing the data included descriptive statistics (n=3), factor analysis (n=3), inferential statistics (n=2), neural network (n=2) and prediction (n=1). Variables influencing game styles were match location (n=1) and team rank (n=1). Game styles was only used to predict team identity (n=1).

2.4 Discussion

The purpose of this systematic review was to describe the traditional and contemporary data capture and analytic methods employed in performance analysis research in team invasion sports, evaluate the practicality of these methods, and formulate practical recommendations on methods for analysing tactics and strategies in team invasion sports. The field of performance analysis has grown quickly in the last decade evident by the marked increase in published research in this period. Sports performance analysis research is undertaken to identify key performance indicators and effective coaching strategies. These indicators and strategies can be developed, trained and improved in practice and implemented in games to increase the chance of success. Emerging patterns in performance analysis techniques largely reflect advancements in technology and perceptions of viewing team sport. The majority of research has focused on recording game actions using hand or computerised notational systems and identifying significant differences between successful and less successful teams to illustrate key performance indicators (Figures 2.3 and 2.4). However, the development of tracking devices has allowed greater emphasis to be placed on spatio-temporal measures resulting in newer themes of research on collective team behaviours, social networks and game styles (Figure 2.3). This approach reflects the view that team invasion sports are now understood to be dynamic, complex systems with opposing teams as interacting parts.

Analysts should now analyse a game using a holistic approach on the premise there is not one way to win a game, or a criterion of performance indicators that can reflect all teams' strategies. Strategies are the plans developed by a team to gain and maintain possession and create (and prevent) goal scoring opportunities (Grehaigne et al., 1999; Hughes & Bartlett, 2002). These strategies are typically built around the key players, their strengths and oppositions weaknesses (Grehaigne et al., 1999), and correspondingly, this is how performance should be captured and analysed.

The basis for all performance analysis techniques begins with the recording of game actions. This approach underpins the abundance of research focusing on game actions in team invasion sports. The limitation of these variables are that they are all outcome-focused, reporting *what* happened in a game, but do not reveal *how* or *why* some action or event occurred. For instance, goal shots are a key performance indicator in soccer (Konefal et al., 2018; Lago-Ballesteros & Lago-Penas, 2010; Lago-Penas et al., 2010) but they don't inform a coach how to create goal scoring opportunities. Although single actions provide benchmarks for key areas of the game, they do not provide insight into how strategies can be developed to achieve these targets and therefore is a less practical approach to analysing performance.

The majority of performance analysis research used inferential statistics to compare the means of game actions of successful and less successful teams, based on match outcome, team rank or stage of tournament, to identify key performance indicators in sports. A key performance indicator is defined as a variable related to success (Hughes & Bartlett, 2002). However, a criticism of traditional statistical tests testing a null hypothesis, is that the p-value may not reflect the true practical significance of the data given a small sample size and large variability (Batterham & Hopkins, 2006). Similar to the development of performance analysis techniques and methodologies the statistical analyses of data continue to evolve. Traditional statistical significance and null hypothesis testing dominates the experimental literature although shortcomings of solely focusing on a p-value in this approach has been raised (Wasserstein et al., 2019). Alternative statistical approaches such as Bayesian estimation or hybrid systems such as magnitude based inferences continue to be debated (Batterham & Hopkins, 2006; Mengersen et al., 2016; Sainani, 2018; Welsh & Knight, 2015). Performance analysts should ensure that analytical approaches and decisions in research and practical settings are well justified, reported transparently and interpreted correctly.

Nonetheless, research into game actions indicates that a successful team must outperform the opposition in key performance indicators highlighted by inferential statistics. For example, in basketball the percentage of successful 3-point shots and free throws made, and defensive rebounds were significantly higher for winning compared to losing teams (Cene, 2018; Csataljay et al., 2012; Garcia et al., 2014). These data indicate that shooting and rebounds are the key actions related to success. This approach is also reflected in studies that developed models to predict match outcome. Ortega et al. (2009) demonstrated that tries scored and conversions made in rugby union were useful in predicting match outcome, correctly classifying 93% of teams as winners or losers. These models can illuminate game variables with higher probabilities of success and be used to classify winning and losing teams or higher and lower ranked teams. However, probability analysis alone does not reflect the strategies employed by individual sides. Grouping teams based on success masks the different strategies employed by teams to achieve the same outcome. In practice, coaches and team analysts need to evaluate key differences within and between teams to understand how to defeat opposing teams.

In contrast, analysing game actions with a dynamic aspect by incorporating space, time or opposition interaction provides context behind these outcome-focused variables. This approach offers greater understanding into team strategy as it provides detail on how a team actually functions under different game constraints. For example, possession is considered a performance indicator in soccer, however more successful teams had greater possession in the middle offensive zone while less successful teams had greater possession in the middle defensive zone (Casal et al., 2017). This outcome highlights where the possession is held is more important than just having greater possession then the opposition. Further analysing game actions per playing position reflects the role each player has in the team based on team strategy. James et al. (2005) reported substantial differences between playing positions in rugby union for passes, tackles, carries and kicks. For example, blindside flankers had 6 more carries per game compared to openside flankers (James et al., 2005). Players should be analysed according to their role in the team to provide an accurate representation of their effect on the game. However, intra-positional differences also highlighted the variations in individual playing styles that must be accounted for when analysing key players in a team (James et al., 2005). Although individual dynamic game actions provide an overview of why a match may have been won or lost and which individual played well or not, they alone do not provide information on team strategies.

Further insight can be gained by employing a process-orientated approach and viewing a sequence of play rather than individual dynamic game actions. Movement patterns reflect these sequences of play in attacking (or defensive) strategies. Patterns of play can be identified for teams that are most likely to lead to a goal scoring opportunity or patterns more likely to lead to a turnover. For example, Sarmento et al. (2018) demonstrated that the most likely pattern of play leading to a goal scoring opportunity in soccer was when a team regained possession in the attacking half using a counter attack and finished with a cross into the box. Sequential analysis in this form is more informative and practical for developing strategies.

Movement patterns can also be identified for specific game events or actions which reflect key moments in a game and are increasingly being investigated in team sports. Identifying successful strategies for key performance indicators increases the chances of converting those opportunities into points or goals. Rather than just identifying whether a variable is a key performance indicator, understanding how to execute these actions effectively provides greater evidence on how to be successful in sport. For example, knowing corner kicks are related to success in soccer (Castellano et al., 2012; Mitrotasios, 2018) illustrates the importance of the set piece. However, a goal shot from a corner kick is more likely to occur if the ball is played indirectly to the far post with 3-4 intervening attackers in a dynamic organisation (Casal et al., 2015), information that provides insight a coach can directly implement in practice.

Inferential statistics have been used to analyse the association of dynamic game actions or possession with outcomes to identify movement patterns more likely to result in favourable consequences such as goal scoring opportunities. In soccer for example, Tenga et al. (2010) used a chi square analysis to examine the association between tactics and score-box possessions. A score box possession was more likely to occur against an imbalanced defence using a counter attack starting in the final third, 5 or more passes including a penetrative pass, compared to elaborate attacks, starting in the middle or first third, 4 or less passes without a penetrative pass (Tenga et al., 2010). Alternatively, the defensive strategy implemented by a team in basketball improved the efficacy of the pick and roll movement, and the defence were more effective at preventing the opposition scoring when employing switch, deny or trap plays and less effective when using the trail and sag tactic (Koutsouridis et al., 2018). Predictive models have also been developed to determine the likelihood of possession or game action outcomes underpinning more successful strategies. For example, Tenga et al.

(2010) used logistic regression and odds ratios to show that counter attacks against an imbalanced defence were predicted to be 2.7 times more likely to result in a goal scoring opportunity then elaborate attacks in soccer. Therefore, inferential and predictive analysis allows key movement patterns to be identified highlighting the critical areas of the game for tactical planning and review.

Measuring entropy or the variability of a team provides an alternate approach to analysing movement patterns. Rather than measuring what teams do consistently there is merit in identifying the variability in patterns which reflects unpredictability. In team invasion sports, there is a delicate balance between being organised and consistent, and being disorganised and unpredictable (Neuman et al., 2018). A team should attempt to retain their attacking organisation but implement enough variability in attacking strategies to increase the difficulty for the opposition defending (Neuman et al., 2018). Nevertheless, being unpredictable has been related to success (Hobbs et al., 2018; Neuman et al., 2018). For example, greater values of entropy were observed in basketball matches with a large deficit win compared to small deficit wins and large deficit losses suggesting the degree of unpredictability is positively related to match outcome (Hobbs et al., 2018). Therefore, understanding the unpredictability of a team is just as important as understanding the consistent patterns a team displays and provides practical insight a coach can use to develop strategies.

Collective team behaviours are also a process-orientated analysis theme, although are more based on team structure then game action based themes like dynamic actions. Tracking devices allow collective team behaviours to be recorded which provide information on how a team moves and is structured during different phases of the game or key moments. How a team is structured provides insight into what strategies they will employ and their effectiveness. For example, in soccer when a team is winning, the players will typically position themselves so their centroid location is closer to their own goal to protect their lead (Clemente, Couceiro, Martins, Mendes et al., 2014). In contrast, losing teams tend to increase the surface area of the team by stretching the lengths and width between players to create space for greater attacking opportunities (Clemente, Couceiro, Martins, Mendes et al., 2014). However, many sports do not have access to semi-automated tracking systems that provide movement data for both teams. Quantifying collective team behaviours may not be a practical option for capturing data from both competing teams, and having access to only one team's GPS data only provides half the match story. Nonetheless, tracking team behaviours provides

spatio-temporal information, and when coupled with notated match events, reveals important details to better understand team strategy.

Team structure will depend on the players within the team. By analysing the individuals within a team and how they connect illustrates how an oppositions team structure can be broken down to impede their tactics. Social network analysis examines the connections within a team. Rather than just identifying how many passes a team has, by highlighting who are the key connections within the team and who generates passes leading to attacks, teams can implement specific strategies to target certain impact players. For example, Clemente et al. (2016) studied the passing networks in relation to goals scored in a single team and identified that the lateral defenders and midfielders were the players most likely to initiate an attack leading to a goal. Thus, an opposition coach can use this information to develop strategies to prevent these players receiving the ball and instruct their team to allow the opposition central defenders to hold possession as they are less likely to create goal scoring plays. However, for those with years of experience in a sport this information may be somewhat obvious. Data analysis should reveal new insights that cannot be gained from live observation, so social network analysis, similar to game actions, should provide greater context or analysis to be useful for coaching staff. Therefore, the context of each pass, such as location on the field and speed of attack, should also be incorporated to identify the key players under different situations. Clemente et al. (2016) further showed that the key regions involved in scoring goals was passing the ball from the attacking wing zones to the central zone outside or inside the penalty box. Together this information highlights this team's strategy of attacking down the wings using their lateral defenders or midfielders and crossing the ball to the penalty box towards their forwards. Therefore, social network analysis is also a process-orientated and practical method of an analysis, providing insight into the intra-team dynamics to illustrate their effect on strategy and game performance.

Rather than focus on outcome-orientated variables, inferential studies exploring collective team behaviours compare spatial variables, time periods in a game or match phase. For example, in Australian Football in offence teams increase their length, width and surface area to create space and uncertainty in the opposition structure (Alexander, Spencer, Mara et al., 2019; Alexander, Spencer, Sweeting et al., 2019). In contrast, in defence they contract to protect the area closest to goal to limit chances of goal scoring opportunities (Alexander, Spencer, Mara et al., 2019; Alexander, Spencer, Sweeting et al., 2019). Likewise, when analysing social networks, positional roles are compared inferentially. In soccer, central

defenders and midfielders have greater values of out degree centrality (deliver a high number of passes) and betweenness centrality (promote connections between players by receiving and passing to another player) than strikers, highlighting the differences in player role between creating and finishing goal scoring plays (Clemente, Couceiro, Martins, Mendes et al., 2014; Clemente et al., 2016; Clemente & Martins, 2017). Although these analytical methods provide a general overview of team dynamics or player roles, in practice the individuality of key players must be also analysed to understand how teams develop strategies around these players or team structures.

Process-orientated variables including spatial dimensions can be displayed visually so that a coach or player does not need to interpret a large set of complex numbers. Dynamic game actions, movement patterns and collective team behaviours can be presented in heat maps or trajectory maps, and social networks in network maps, to provide a more efficient and practical way of displaying the data. For instance, Stockl and Morgan (2013) illustrated differences between goal scoring capabilities of field hockey teams by tracking their ball movements and displaying this in a contour heat map. The less successful teams, which had fewer goal shots had greater possession in the defensive half of the field, whereas the more successful teams had greater possession in the attacking half (Stockl & Morgan, 2013). More specifically, individual strategies could be identified with the top-ranked team having a higher proportion of possession down the left-hand side of the field compared to the 2nd and 3rd ranked teams who utilised the right-hand side more often (Stockl & Morgan, 2013). Not only do these process-orientated variables provide greater detail then outcome-oriented game actions, the usefulness of visualising this data makes them a practical tool for analysing team strategy.

Analysing a game style rather than individual game actions is reflective of how teams develop strategies and review a performance. A game style can reflect the strengths and weaknesses of a team by highlighting what, where and how a team attacks and defends by grouping common variables into easy to understand team profiles. Understanding a team's way of playing allows an analyst to uncover the strategies used by that team and identify the key dynamic game actions that reflect or measure that team's performance. For example, in soccer common game styles are possession and direct play (Gollan et al., 2018), measuring percentage of possession a team has is only insightful for teams playing a possession game. Teams playing a direct style prefer to counter attack and therefore don't need high levels of possession to be successful. Thus, the interaction of dynamic game actions, collective team

behaviours and passing networks in a game style reflects the holistic nature of team invasion sport providing a practical way of developing strategies.

The application of more advanced data analytical techniques has allowed the game to be viewed in a more holistic manner to reflect the dynamic, complex interactions that occur during team invasion sport. Factor analysis allows a large number of variables to be combined into a few factors with common variance. Similarly, neural networks can employ clustering techniques to group like variables. These methods aggregate and summarise the complex variables into team strategies during different phases of the game, as opposed to viewing individual isolated components. Game styles can consequently be identified from the combination of high and low prominent strategies which are common between teams. This process allows a coach to understand the key tactics for each team based on the understanding of that game style without having to interpret a large set of individual numbers. Game styles can be based on different phases of play such as in soccer and Australian Football, where five moments of play have been identified; established attack, transition attack, transition defence, established defence and set pieces (Gollan et al., 2018; Greenham et al., 2017). Alternatively, game actions can be used to construct the game styles such as in rugby union, where a ball carrying high contact game style and a low possession kicking game style were identified as winning strategies for different teams (Croft et al., 2015). Identifying the key strategies for each game style allows an analyst to understand which variables are important to measure for each team. An analyst may then provide adequate information on whether their team is executing their game plan effectively and inhibiting the key tactics for the opposition. Analysing a game style is a practical method of performance analysis as it evaluates the interaction of game actions, players, opposition and match situation to identify the key strategies for individual teams.

When analysing any data set, it is also important to account for the match situational factors as strategies can change under different conditions. Match location must be considered as teams are likely to have an advantage when playing at home compared to when playing away. For example, in handball, teams playing at home made fewer errors than teams playing away (Krawczyk, 2015). The quality of the opposition must also be considered. When stronger teams play weaker teams the differences between winners and losers can be exaggerated. In contrast, there a fewer differences when similar ranked teams are competing. Normative data can be produced depending on the quality of the opposition to reflect realistic outcome targets. This approach has been demonstrated in netball, where performance was

evaluated using percentiles. If a top ranked team forced 54 turnovers against another top ranked team this is considered to be rated as a similar percentile performance compared to forcing 73 turnovers against a bottom ranked team (O'Donoghue et al., 2008). Similarly, score difference has also been accounted for, and cluster analysis techniques can be used to separate the games into close, balanced and unbalanced games based on the score difference. Several discriminating performance indicators were identified when separating the games based on score difference in basketball; the bigger the score difference between the teams the higher the number of performance indicators identified (Csataljay et al., 2012). Most importantly match status must be recorded as it is likely to have the greatest effect on a team strategy during a game, especially once a goal has been scored in low scoring sports. For example, soccer teams that are losing will typically have greater possession of the ball than teams leading or drawing (Konefal et al., 2018; Lago, 2009). Therefore, match situation must be considered when interpreting results given its influence on team strategy.

Game variables should be recorded in relation to time, space and interaction with the opposition to provide adequate information on each game action to understand how and why that possession outcome occurred. However, the interactions between these complex variables must be analysed to reflect the different styles of play that can be observed - this approach provides information a coach can use to develop and implement strategies. Teams should be viewed individually against the different criteria to identify their strengths and weaknesses, differences and similarities, accounting for match status, quality of opposition and match location. Measuring within-team behaviours through passing networks should provide greater insight into how a team plays based on the strengths and weaknesses of individuals within the team. Although in-depth information needs to be collected, condensing it into summarised team profiles is necessary to provide holistic recommendations on strategies used by individual teams. The performance analysis techniques should provide the greatest impact in a practical setting by capturing expansive detail and presenting it in a simple, practical manner that a coach can use to develop strategies.

In conclusion, performance analysis techniques have evolved substantially in the last decade given advancements in technology and perceptions of team sport. It is now recognised that team invasion sport is dynamic and complex, and analysis methods must reflect this to ensure effective outcomes and recommendations for enhancing team performance. Analysis methods should capture performance as dynamic game actions and use data aggregation techniques such as factor analysis or neural networks to simplify complex information into holistic game

styles. The aim here is to present a practical summary of the key strategies implemented by teams. Teams must be viewed as individual entities and the key players and interactions within the team identified. These performance analysis approaches are useful for understanding the strengths and weaknesses of each team and ultimately for developing effective strategies for team invasion sports.

2.5 References

1. Alexander, J.P., Spencer, B., Mara, J.K., & Robertson, S. (2019). Collective team behaviour of Australian Rules football during phases of match play. *Journal of Sports Sciences,* 37(3), 237-243.
2. Alexander, J.P., Spencer, B., Sweeting, A.J., Mara, J.K., & Robertson, S. (2019). The influence of match phase and field position on collective team behaviour in Australian Rules football. *Journal of Sports Sciences,* 37(2), 1699-1707.
3. Batterham, A.M., & Hopkins, W.G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance,* 1(1), 50-57.
4. Casal, C.A., Maneiro, R., Arda, T., Losada, J.L., & Rial, A. (2015). Analysis of corner kick success in elite football. *International Journal of Performance Analysis in Sport,* 15(2), 430-451.
5. Casal, C.A., Maneiro, R., Arda, T., Mari, F.J., & Losada, J.L. (2017). Possession zone as a performance indicator in football. The game of the best teams. *Frontiers in Psychology,* 8(1), 1-11.
6. Castellano, J., Casamichana, D., & Lago, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *Journal of Human Kinetics,* 31(1), 139-147.
7. Çene, E. (2018). What is the difference between a winning and a losing team: Insights from Euroleague basketball. *International Journal of Performance Analysis in Sport,* 18(1), 55-68.
8. Clemente, F.M., Couceiro, M.S., Martins, F.M.L., Mendes, R., & Figueiredo, A.J. (2013). Measuring collective behaviour in football teams: Inspecting the impact of each half of the match on ball possession. *International Journal of Performance Analysis in Sport,* 13(3), 678-689.
9. Clemente, F.M., Couceiro, M.S., Martins, F.M.L., & Mendes, R.S. (2014). Using network metrics to investigate football team players' connections: A pilot study. *Motriz: Journal of Physical Education,* 20(3), 262-271.
10. Clemente, F.M., Couceiro, M.S., Martins, F.M.L., Mendes, R.S., & Figueiredo, A.J. (2014). Using collective metrics to inspect spatio-temporal relationships between football players. *South African Journal for Research in Sport Physical,* 36(2), 47-59.
11. Clemente, F.M., Martins, F.M.L., & Mendes, R.S. (2016). Analysis of scored and conceded goals by a football team throughout a season: A network analysis. *Kinesiology*, 48(1), 103-114.

12. Clemente, F.M., Martins, F.M.L., Wong, D.P., Kalamaras, D., & Mendes, R.S. (2015). Midfielder as the prominent participant in the building attack: A network analysis of national teams in FIFA World Cup 2014. *International Journal of Performance Analysis in Sport,* 15(2), 704-22.
13. Clemente, F.M., & Martins, F.M.L. (2017). Who are the prominent players in the UEFA champions league? An approach based on network analysis. *Walailak Journal of Science and Technology,* 14(8), 627-636.
14. Costa, G.D.C.T., Pedrosa, G.F., Souza, N., Gemente, F.R.F., Freire, A.B., & Castro H. (2017). Type of game practiced in handball according to the positions of the attackers: Analysis of the women's world handball championship 2015. *International Journal of Performance Analysis in Sport,* 17(3), 360-373.
15. Croft, H., Lamb, P., & Middlemas, S. (2015). The application of self-organising maps to performance analysis data in rugby union. *International Journal of Performance Analysis in Sport,* 15(3), 1037-1046.
16. Csataljay, G., James, N., Hughes, M., & Dancs, H. (2012). Performance differences between winning and losing basketball teams during close, balanced and unbalanced quarters. *Journal of Human Sport and Exercise,* 7(2), 356-364.
17. Diana, B., Zurloni, V., Elia, M., Cavalera, C.M., Jonsson, G.K., & Teresa Anguera, M. (2017). How game location affects soccer performance: T-pattern analysis of attack actions in home and away matches. *Frontiers in Psychology,* 8(1), 1-11.
18. Dutt-Mazumder, A., Button, C., Robins, A., & Bartlett, R. (2011). Neural network modelling and dynamical system theory. Are they relevant to study the governing dynamics of association football players? *Sports Medicine,* 41(12), 1003-1017.
19. Fernandez-Navarro, J., Fradua, L., Zubillaga, A., Ford, P.R., & McRobert, A.P. (2016). Attacking and defensive styles of play in soccer: Analysis of Spanish and English elite teams. *Journal of Sports Sciences,* 34(24), 2195-2204.
20. Garcia, J., Ibanez, S.J., Gomez, M.A., & Sampaio, J. (2014). Basketball game-related statistics discriminating ACB league teams according to game location, game outcome and final score differences. *International Journal of Performance Analysis in Sport,* 14(2), 443-452.
21. Gollan, S., Ferrar, K., & Norton, K. (2018). Characterising game styles in the English Premier League using the "moments of play" framework. *International Journal of Performance Analysis in Sport,* 18(6), 998-1009.

22. Greenham, G., Hewitt, A., & Norton, K. (2017). A pilot study to measure game style within Australian football. *International Journal of Performance Analysis in Sport,* 17(4), 576-585.
23. Gréhaigne, J.-F., Godbout, P., & Bouthier, D. (1999). The foundations of tactics and strategy in team sports. *Journal of Teaching in Physical Education,* 18(2), 159-174.
24. Grunz, A., Memmert, D., & Perl, J. (2012). Tactical pattern recognition in soccer games by means of special self-organizing maps. *Human Movement Science,* 31(2), 334-343.
25. Hewitt, A., Greenham, G., & Norton, K. (2016). Game style in soccer: What is it and can we quantify it? *International Journal of Performance Analysis in Sport,* 16(1), 355-372.
26. Hobbs, W., Morgan, S., Gorman, A.D., Mooney, M., & Freeston, J. (2018). Playing unpredictably: Measuring the entropy of ball trajectories in international women's basketball. *International Journal of Performance Analysis in Sport,* 18(1), 115-126.
27. Hughes, M.D., & Bartlett, R.M. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences*, 20(10), 739-754.
28. James, N., Mellalieu, S.D., & Jones, N.M. (2005). The development of position-specific performance indicators in professional rugby union. *Journal of Sports Sciences,* 23(1), 63-72.
29. Konefal, M., Chmura, P., Zacharko, M., Chmura, J., Rokita, A., & Andrzejewski, M. (2018). Match outcome vs match status and frequency of selected technical activities of soccer players during UEFA Euro 2016. *International Journal of Performance Analysis in Sport,* 18(4), 568-581.
30. Koutsouridis, C., Karamousalidis, G., & Galazoulas, C. (2018). The efficacy of "high pick and roll" in relation to the defence's reaction and its effect on the result of the game. *International Journal of Performance Analysis in Sport,* 18(4), 554-567.
31. Kraak, W.J., & Welman, K.E. (2014). Ruck-play as performance indicator during the 2010 Six Nations Championship. *International Journal of Sports Science & Coaching,* 9(3), 525-538.
32. Krawczyk, P. (2015). Technical errors and the venue of the match in handball. *Polish Journal of Sport & Tourism*. 22(1), 25-29.
33. Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences,* 27(13), 1463-1469.
34. Lago-Ballesteros, J., & Lago-Penas, C. (2010). Performance in team sports: Identifying the keys to success in soccer. *Journal of Human Kinetics,* 25(1), 85-91.

35. Lago-Penas, C., Lago-Ballesteros, J., Dellal, A., & Gomez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *The Journal of Sports Science and Medicine,* 9(2), 288-293.
36. Laird, P., & Sutherland, P. (2003). Penalty corners in field hockey: A guide to success. *International Journal of Performance Analysis in Sport,* 3(1), 19-26.
37. Lamas, L., Barrera, J., Otranto, G., & Ugrinowitsch, C. (2014). Invasion team sports: Strategy and match modeling. *International Journal of Performance Analysis in Sport,* 14(1), 307-329.
38. Liebermann, D.G., Katz, L., Hughes, M.D., Bartlett, R.M., McClements, J., & Franks, I.M. (2002). Advances in the application of information technology to sport performance. *Journal of Sports Sciences,* 20(10), 755-769.
39. Mara, J.K., Wheeler, K.W., & Lyons, K. (2012). Attacking strategies that lead to goal scoring opportunities in high level women's football. *International Journal of Sports Science & Coaching,* 7(3), 565-578.
40. Marmarinos, C., Apostolidis, N., Kostopoulos, N., & Apostolidis, A. (2016). Efficacy of the 'pick and roll' offense in top level European basketball teams. *Journal of Human Kinetics,* 50(2), 121-129.
41. McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. *International Journal of Performance Analysis in Sport,* 9(1), 128-140.
42. McGarry, T., Anderson, D.I., Wallace, S.A., Hughes, M.D., & Franks, I.M. (2002). Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences*, 20(10), 771-781.
43. McLean, S., Salmon, P.M., Gorman, A.D., Stevens, N.J., & Solomon, C. (2018). A social network analysis of the goal scoring passing networks of the 2016 European Football Championships. *Human Movement Science*, 57, 400-408.
44. Mengersen, K.L., Drovandi, C.C., Robert, C.P., Pyne, D.B., Gore, C.J., & Chen C.W.S. (2016). Bayesian estimation of small effects in exercise and sports science. *PloS One,* 11(4), e0147311.
45. Mitrotasios, M. (2018). Differences in performance indicators between successful and unsuccessful teams in UEFA-EURO 2012. *Biology of Exercise,* 14(1), 11-22.
46. Neuman, Y., Israeli, N., Vilenchik, D., & Cohen, Y. (2018). The adaptive behavior of a soccer team: An entropy-based analysis. *Entropy,* 20(10), 1-12.
47. O'Donoghue, P. (2006). The use of feedback videos in sport. *International Journal of Performance Analysis in Sport,* 6(2), 1-14.

48. O'Donoghue, P., Mayes, A., Edwards, K.M., & Garland, J. (2008). Performance norms for British National Super League Netball. *International Journal of Sports Science & Coaching,* 3(4), 501-511.
49. Ortega, E., Villarejo, D., & Palao, J.M. (2009). Differences in game statistics between winning and losing rugby teams in the Six Nations Tournament. *The Journal of Sports Science and Medicine,* 8(4), 523-527.
50. Reed, D., & Hughes, M. (2006). An exploration of team sport as a dynamical system. *International Journal of Performance Analysis in Sport.* 6(2), 114-125.
51. Reep, C., & Benjamin, B. (1968). Skill and chance in association football. *Journal of Royal Statistical Society. Series A (General),* 131(4), 581-585.
52. Sainani, K.L. (2018). The problem with "Magnitude-based inference". *Medicine & Science in Sports & Exercise,* 50(10), 2166-2176.
53. Salmon, P.M., & McLean, S. (2020). Complexity in the beautiful game: Implications for football research and practice. *Science and Medicine in Football*, 4(2), 162-167.
54. Sarmento, H., Figueiredo, A., Lago-Penas, C., Milanovic, Z., Barbosa, A., Tadeu, P., & Bradley, P.S. (2018). Influence of tactical and situational variables on offensive sequences during elite football matches. *Journal of Strength and Conditioning Research,* 32(8), 2331-2339.
55. Stöckl, M., & Morgan, S. (2013). Visualization and analysis of spatial characteristics of attacks in field hockey. *International Journal of Performance Analysis in Sport,* 13(1), 160-78.
56. Sunderland, C., Bussell, C., Atkinson, G., Alltree, R., & Kates, M. (2006). Patterns of play and goals scored in international standard women's field-hockey. *International Journal of Performance Analysis in Sport,* 6(1), 13-29.
57. Tenga, A., Holme, I., Ronglan, L.T., & Bahr, R. (2010). Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. *Journal of Sports Sciences,* 28(3), 245-255.
58. Travassos, B., Davids, K., Araujo, D., & Esteves, P.T. (2013). Performance analysis in team sports: Advances from an ecological dynamics approach. *International Journal of Performance Analysis in Sport,* 13(1), 83-95.
59. Vilar, L., Araujo, D., Davids, K., & Bar-Yam, Y. (2013). Science of winning soccer: Emergent pattern-forming dynamics in association football. *Journal of Systems Science and Complexity,* 26(1), 73-84.
60. Wasserstein, R.L., Schirm, A.L., & Lazar, N.A. (2019). Moving to a world beyond "p< 0.05". *The American Statistician,* 73(Suppl1), 1-19.

61. Welsh, A.H., & Knight, E.J. (2015). “Magnitude-based inference”: A statistical review. *Medicine & Science in Sports & Exercise,* 47(4), 874.
62. Wright, C., Atkins, S., Jones, B., & Todd, J. (2013). The role of performance analysts within the coaching process: Performance analysts survey ‘The role of performance analysts in elite football club settings’. *International Journal of Performance Analysis in Sport,* 13(1), 240-261.

2.6 Supplementary Resources

Supplementary Resource 2.1 Index of Performance Analysis Articles. Article numbers refer to reference numbers listed in Supplementary Resource 2.2.

Sport	Theme	Article Reference Numbers
Australian Football	Game Actions	Descriptive: 1, 2, 3, 4, 5 Inferential: 6, 7, 8, 9 Prediction: 3, 5, 6, 8, 10, 11 Other: 9
	Dynamic Game Actions	Descriptive: 12, 13 Inferential: 12 Prediction: 13
	Movement Patterns	Inferential: 14 Prediction: 15
	Collective Team Behaviours	Inferential: 16 Other: 17
	Game Styles	Descriptive: 18 Inferential: 18
Basketball	Game Actions	Descriptive: 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31 Inferential: 22, 23, 25, 28, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60 Prediction: 20, 21, 23, 24, 27, 29, 30, 32, 34, 45, 46, 48, 49, 50, 51, 52, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, Other: 22, 28, 31, 34, 35, 37, 41, 47, 50, 66, 68, 70, 71
	Dynamic Game Actions	Descriptive: 72, 73, 74 Inferential: 73, 75, 76, 77, 78, 79, 80, 81 Prediction: 73, 74, 78, 79, 80, 81, 82, 83 Other: 77, 84
	Movement Patterns	Descriptive: 85, 86, 87, 88, 89, 90, 91, 92, 93, 94

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Sport	Theme	Article Reference Numbers
		Inferential: 91, 92, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119 Prediction: 87, 89, 90, 98, 101, 102, 103, 106, 107, 113, 120, 121, 122 Other: 107, 108, 109, 116, 122
	Collective Team Behaviours	Other: 123, 124
	Social Network Analysis	Inferential: 125
Field Hockey	Game Actions	Inferential: 126
	Dynamic Game Actions	Inferential: 127
	Movement Patterns	Descriptive: 128, 129, 130 Inferential: 131, 132, 133, 134 Other: 135
	Social Network Analysis	Descriptive: 136
Futsal	Game Actions	Descriptive: 137, 138 Inferential: 137, 139
	Dynamic Game Actions	Descriptive: 140 Inferential: 140, 141, 142 Prediction: 140
	Movement Patterns	Descriptive: 143 Inferential: 143, 144 Prediction: 143
	Collective Team Behaviours	Inferential: 145 Other: 145
Gaelic Football	Game Actions	Descriptive: 146 Inferential: 146, 147, 148 Prediction: 147 Other: 148
	Dynamic Game Actions	Inferential: 149

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Sport	Theme	Article Reference Numbers
	Movement Patterns	Inferential: 150
Handball	Game Actions	Descriptive: 151, 152, 153, 154, 155, 156 Inferential: 151, 152, 154, 157, 158, 159, 160, 161, 162, 163 Prediction: 156, 158 Other: 160, 161
	Dynamic Game Actions	Descriptive: 164, 165, 166, 167, 168, 169, 170 Inferential: 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182 Prediction: 165, 169, 171, 174, 177, 178, 179
	Movement Patterns	Descriptive: 183, 184, 185, 186 Inferential: 184, 187, 188, 189, 190 Prediction: 187, 190, 191 Other: 185, 190, 191, 192
Netball	Game Actions	Descriptive: 193 Inferential: 194 Other: 194, 195, 196
	Dynamic Game Actions	Inferential: 197
	Movement Patterns	Inferential: 198
Rugby League	Game Actions	Inferential: 199, 200, 201, 202, 203 Prediction: 202, 203, 204, 205 Other: 200, 201, 202, 204
	Dynamic Game Actions	Descriptive: 206 Inferential: 207 Prediction: 206
	Movement Patterns	Inferential: 208
Rugby Sevens	Game Actions	Descriptive: 209, 210, 211 Inferential: 209, 210, 211, 212, 213
	Dynamic Game Actions	Inferential: 214

Supplementary Resource 2.1 continued

Sport	Theme	Article Reference Numbers
	Movement Patterns	Inferential: 215, 216 Prediction: 216
Rugby Union	Game Actions	Descriptive: 217, 218, 219, 220, 221 Inferential: 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243 Prediction: 218, 227, 234, 238, 239, 242, 244, 245, 246, 247 Other: 234, 238, 239, 240, 248
	Dynamic Game Actions	Descriptive: 249, 250 Inferential: 250, 251, 252, 253, 254, 255 Prediction: 255 Other: 256
	Movement Patterns	Descriptive: 257, 258 Inferential: 259, 260, 261, 262, 263, 264, 265, 266, 267
	Game Styles	Other: 268
Soccer	Game Actions	Descriptive: 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286 Inferential: 271, 272, 274, 276, 278, 280, 282, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342 Prediction: 271, 273, 275, 276, 277, 279, 281, 300, 312, 316, 320, 323, 324, 325, 326, 329, 331, 332, 338, 339, 341, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357 Other: 278, 279, 344, 350, 353, 358, 359, 360

Supplementary Resource 2.1 continued

Sport	Theme	Article Reference Numbers
	Dynamic Game Actions	Descriptive: 361, 362, 363, 364, 365 Inferential: 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387 Prediction: 366, 380, 381, 382, 388, 389, 390, 391, 392, 393, 394 Other: 361, 362, 370, 375, 389, 391, 395, 396
	Movement Patterns	Descriptive: 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408 Inferential: 400, 401, 402, 403, 404, 405, 406, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445 Prediction: 410, 411, 416, 417, 418, 422, 436, 439, 440, 441, 444, 446, 447, 448, 449, 450, 451 Other: 404, 447, 450, 452
	Collective Team Behaviours	Descriptive: 453, 454, 455, 456, 457 Inferential: 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471 Prediction: 472 Other: 456, 457, 466, 467, 468, 472, 473, 474, 475
	Social Network Analysis	Descriptive: 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487 Inferential: 478, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498 Prediction: 499 Other: 476, 479, 480, 482, 483, 484, 485, 496, 500
	Game Styles	Descriptive: 501, 502 Inferential: 503 Prediction: 504

Supplementary Resource 2.1 continued

Sport	Theme	Article Reference Numbers
		Other: 501, 502, 503, 505
Water polo	Game Actions	Descriptive: 506 Inferential: 507, 508, 509, 510 Prediction: 506, 509
	Dynamic Game Actions	Descriptive: 511 Inferential: 511, 512, 513, 514, 515, 516, 517, 518, 519 Prediction: 512, 513, 515, 516, 517, 518, 520 Other: 518
	Movement Patterns	Descriptive: 521 Inferential: 521
	Social Network Analysis	Descriptive: 522 Inferential: 522
Other	Game Actions	Descriptive: 523, 524 Inferential: 523, 525, 526, 527, 528 Prediction: 526, 527, 529 Other: 525, 526
	Dynamic Game Actions	Descriptive: 530, 531 Inferential: 530, 532, 533
	Movement Patterns	Inferential: 534, 535, 536 Prediction: 537 Other: 536

Supplementary Resource 2.2 Extended Reference List. Includes all articles identified from the systematic review, including those not directly cited in text.

1. Appleby B, Dawson B. Video analysis of selected game activities in Australian Rules Football. J Sci Med Sport. 2002;5(2):129-42.
2. Dawson B, Hopkinson R, Appleby B, Stewart G, Roberts C. Player movement patterns and game activities in the Australian Football League. J Sci Med Sport. 2004;7(3):278-91.
3. McIntosh S, Kovalchik S, Robertson S. Validation of the Australian Football League player ratings. Int J Sports Sci Coach. 2018;13(6):1064-71.
4. Rennie MJ, Watsford ML, Spurrs RW, Kelly SJ, Pine MJ. Phases of match-play in professional Australian Football: Descriptive analysis and reliability assessment. J Sci Med Sport. 2018;21(6):635-9.
5. Robertson S, Gupta R, McIntosh S. A method to assess the influence of individual player performance distribution on match outcome in team sports. J Sport Sci. 2016;34(19):1893-900.
6. Hiscock D, Dawson B, Heasman J, Peeling P. Game movements and player performance in the Australian Football League. Int J Perf Anal Sport. 2012;12(3):531-45.
7. Lorains M, Ball K, MacMahon C. Performance analysis for decision making in team sports. Int J Perf Anal Sport. 2013;13(1):110-9.
8. Robertson S, Back N, Bartlett JD. Explaining match outcome in elite Australian Rules Football using team performance indicators. J Sport Sci. 2016;34(7):637-44.
9. Woods CT, Robertson S, Collier NF. Evolution of game-play in the Australian Football League from 2001 to 2015. J Sport Sci. 2017;35(19):1879-87.
10. Woods CT. The use of team performance indicator characteristics to explain ladder position at the conclusion of the Australian Football League home and away season. Int J Perf Anal Sport. 2016;16(3):837-47.
11. Young CM, Luo W, Gastin P, Tran J, Dwyer DB. The relationship between match performance indicators and outcome in Australian Football. J Sci Med Sport. 2019;22(4):467-71.
12. Heasman J, Dawson B, Berry J, Stewart G. Development and validation of a player impact ranking system in Australian Football. Int J Perf Anal Sport. 2008;8(3):156-71.
13. McIntosh S, Kovalchik S, Robertson S. Examination of player role in the Australian Football League using match performance data. Int J Perf Anal Sport. 2018;18(3):451-62.
14. Anderson D, Breed R, Spittle M, Larkin P. Factors affecting set shot goal-kicking performance in the Australian Football League. Percept Mot Ski. 2018;125(4):817-33.
15. O'Shaughnessy DM. Possession versus position: Strategic evaluation in AFL. J Sport Sci Med. 2006;5(4):533-40.
16. Alexander JP, Spencer B, Mara JK, Robertson S. Collective team behaviour of Australian Rules Football during phases of match play. J Sport Sci. 2019;37(3):237-43.
17. Alexander JP, Spencer B, Sweeting AJ, Mara JK, Robertson S. The influence of match phase and field position on collective team behaviour in Australian Rules Football. J Sport Sci. 2019;37(2): 1699-1707.
18. Greenham G, Hewitt A, Norton K. A pilot study to measure game style within Australian Football. Int J Perf Anal Sport. 2017;17(4):576-85.
19. García-Manso JM, Martín-González JM, De Saá Guerra Y, Valverde T, Jiménez SL. Last minute in NBA games. Rev Psicol Deporte. 2015;24(3):31-5.
20. Gomez M-A, Ortega E, Jones G. Investigation of the impact of 'fouling out' on teams' performance in elite basketball. Int J Perf Anal Sport. 2016;16(3):983-94.
21. Gómez M-Á, Silva R, Lorenzo A, Kreivyte R, Sampaio J. Exploring the effects of substituting basketball players in high-level teams. J Sport Sci. 2017;35(3):247-54.

22. Gomez MA, Jimenez S, Navarro R, Lago-Penas C, Sampaio J. Effects of coaches' timeouts on basketball teams' offensive and defensive performances according to momentary differences in score and game period. Eur J Sport Sci. 2011;11(5):303-8.
23. Ibanez SJ, Gonzalez-Espinosa S, Feu S, Garcia-Rubio J. Basketball without borders? Similarities and differences among continental basketball championships. Rev Int Cienc Deporte. 2018;14(51):42-54.
24. Jukic I, Milanovic D, Vuleta D, Bracic M. Evaluation of variables of shooting for a goal recorded during the 1997 European Basketball Championship in Barcelona. Kinesiology. 2000;32(2):51-62.
25. Lidor R, Arnon M. Developing indexes of efficiency in basketball: Talk with the coaches in their own language. Kinesiology. 2000;32(2):31-41.
26. Lorenzo J, Lorenzo A, Conte D, Gimenez M. Long-term analysis of elite basketball players' game-related statistics throughout their careers. Front Psychol. 2019;10(1):1-6.
27. Ozmen MU. Marginal contribution of game statistics to probability of winning at different levels of competition in basketball: Evidence from the Euroleague. Int J Sports Sci Coach. 2016;11(1):98-107.
28. Parejo I, Garcia A, Antunez A, Ibanez S. Differences in performance indicators among winners and losers of group a of the Spanish basketball amateur league (EBA). Rev Psicol Sports. 2013;22(1):257-61.
29. Paulauskas R, Masiulis N, Vaquera A, Figueira B, Sampaio J. Basketball game-related statistics that discriminate between European players competing in the NBA and in the Euroleague. J Hum Kinet. 2018;65(1):225-33.
30. Sampaio J, Lago-Penas C, Gomez MA. Brief exploration of short and mid-term timeout effects on basketball scoring according to situational variables. Eur J Sport Sci. 2013;13(1):25-30.
31. Sporiš G, Šango J, Vučpeti V, Mašina T. The latent structure of standard game efficiency indicators in basketball. Int J Perf Anal Sport. 2006;6(1):120-9.
32. Angel Gomez M, Gasperi L, Lupo C. Performance analysis of game dynamics during the 4th game quarter of NBA close games. Int J Perf Anal Sport. 2016;16(1):249-63.
33. Čaušević D. Game-related statistics that discriminate winning and losing teams from the world championships in Spain in 2014. Homo Sport. 2015;17(2):16-9.
34. Çene E. What is the difference between a winning and a losing team: Insights from Euroleague basketball. Int J Perf Anal Sport. 2018;18(1):55-68.
35. Conte D, Lukonaitiene I. Scoring strategies differentiating between winning and losing teams during FIBA EuroBasket women 2017. Sports. 2018;6(2):1-9.
36. Conte D, Tessitore A, Gjullin A, Mackinnon D, Lupo C, Favero T. Investigating the game-related statistics and tactical profile in NCAA division I men's basketball games. Biol Sport. 2018;35(2):137-43.
37. Csataljay G, O'Donoghue P, Hughes M, Dancs H. Performance indicators that distinguish winning and losing teams in basketball. Int J Perf Anal Sport. 2009;9(1):60-6.
38. De Rose D. Statistical analysis of basketball performance indicators according to home/away games and winning and losing teams. J Hum Move Stud. 2004;47(4):327-36.
39. dos Santos YYS, Monezi LA, Misuta MS, Mercadante LA. Technical indicators registered as a function of the playing time in Brazilian basketball. Rev Bras Cineantropom Desempenho Hum. 2018;20(2):172-81.
40. García J, Ibáñez SJ, Feu S. Game statistics that discriminate the national teams participating in the 2006 World Basketball Championship, regarding the level and the gender of the teams. Rev Kronos. 2010;9(17):57-63.

41. Garcia J, Ibanez SJ, Gomez MA, Sampaio J. Basketball game-related statistics discriminating ACB league teams according to game location, game outcome and final score differences. Int J Perf Anal Sport. 2014;14(2):443-52.
42. Guimaraes E, Santos A, Santos E, Tavares F, Janeira MA. National Players vs. foreign players: What distinguishes their game performances? A study in the Portuguese Basketball League. Rev Int Cienc Deporte. 2018;14(54):374-81.
43. Ibanez SJ, Garcia-Rubio J, Gomez M-A, Gonzalez-Espinosa S. The impact of rule modifications on elite basketball teams' performance. J Hum Kinet. 2018;64(1):181-93.
44. Kalen A, Perez-Ferreiros A, Rey E, Padron-Cabo A. Senior and youth national team competitive experience: Influence on player and team performance in European basketball championships. Int J Perf Anal Sport. 2017;17(6):832-47.
45. Karipidis A, Fotinakis P, Taxildaris K, Fatouros J. Factors characterizing a successful performance in basketball. J Hum Move Stud. 2001;41(5):385-97.
46. Koh Koon T, Wang CKJ, Mallett CJ. Discriminating factors between successful and unsuccessful elite youth Olympic female basketball teams. Int J Perf Anal Sport. 2012;12(1):119-31.
47. Kreivytė R, Čižauskas A. Differences of indicators in competitive performance between winning and losing teams in basketball. Educ Phys Train Sport. 2010;77(2):41-8.
48. Leicht AS, Gomez MA, Woods CT. Team performance indicators explain outcome during women's basketball matches at the Olympic games. Sports. 2017;5(4):1-8.
49. Leicht AS, Gómez MA, Woods CT. Explaining match outcome during the men's basketball tournament at the Olympic games. J Sport Sci Med. 2017;16(4):468-73.
50. Lorenzo A, Angel Gomez M, Ortega E, Jose Ibanez S, Sampaio J. Game related statistics which discriminate between winning and losing under-16 male basketball games. J Sport Sci Med. 2010;9(4):664-8.
51. Madarame H. Basketball game-related statistics that discriminate among continental championships for under-18 women. Sports. 2018;6(4):1-9.
52. Madarame H. Regional differences in women's basketball: A comparison among continental championships. Sports. 2018;6(3):1-11.
53. Malarranha J, Figueira B, Leite N, Sampaio J. Dynamic modelling of performance in basketball. Int J Perf Anal Sport. 2013;13(2):377-87.
54. Meneses LR, Gois Junior LEM, De Almeida MB. Performance analysis of Brazilian basketball along the three seasons of Brazilian National Basketball League. Rev Bras Cienc Esporte. 2016;38(1):93-100.
55. Nunes JA, Aoki MS, Altimari LR, Petroski EL, de Rose Júnior D, Montagner PC. Anthropometric profile and indicators of playing performance in Brazilian women's Olympic basketball teams. Rev Bras Cineantropom Desempenho Hum. 2009;11(1):67-72.
56. Perez-Ferreiros A, Kalen A, Rey E. Short- and mid-term effects of the 2010 rule changes on game-related statistics in European basketball championships: An interrupted time series analysis. Int J Sports Sci Coach. 2018;13(6):1081-9.
57. Puente C, Del Cosol J, Salinero JJ, Abian-Vicen J. Basketball performance indicators during the ACB regular season from 2003 to 2013. Int J Perf Anal Sport. 2015;15(3):935-48.
58. Romarís IU, Refoyo I, Lorenzo J. Comparison of the game rhythm in Spanish Female League and ACB League. Cuad Psicol Deporte. 2016;16(2):161-8.
59. Sampaio J, Janeira M. Statistical analyses of basketball team performance: Understanding teams' wins and losses according to a different index of ball possessions. Int J Perf Anal Sport. 2003;3(1):40-9.
60. Sampaio J, Lago C, Drinkwater EJ. Explanations for the United States of America's dominance in basketball at the Beijing Olympic Games (2008). J Sport Sci. 2010;28(2):147-52.

61. Aharoni G, Sarig OH. Hot hands and equilibrium. Appl. Econ. 2012;44(18):2309-20.
62. Baghal T. Are the "four factors" indicators of one factor? An application of structural equation modeling methodology to NBA data in prediction of winning percentage. J Quant Anal Sports. 2012;8(1):1-14.
63. Casals M, Martinez JA. Modelling player performance in basketball through mixed models. Int J Perf Anal Sport. 2013;13(1):64-82.
64. Gomez MA, Ibanez SJ, Parejo I, Furley P. The use of classification and regression tree when classifying winning and losing basketball teams. Kinesiology. 2017;49(1):47-56.
65. Lam MWY. One-match-ahead forecasting in two-team sports with stacked bayesian regressions. J Artif Intell Soft Comput Res. 2018;8(3):159-71.
66. Mikolajec K, Maszczyk A, Zajac T. Game indicators determining sports performance in the NBA. J Hum Kinet. 2013;37(1):145-51.
67. Prochnow RA, Reale VMC, Santos YYS, Monezi LA, Mercadante LA. Analysis of performance indicators that discriminate winning and losing teams in new basketball Brazil. Sport Tk-Rev Euroam Cienc Deporte. 2017;6(1):207-12.
68. Sampaio J, Lago C, Casais L, Leite N. Effects of starting score-line, game location, and quality of opposition in basketball quarter score. Eur J Sport Sci. 2010;10(6):391-6.
69. Zimmermann A. Basketball predictions in the NCAAB and NBA: Similarities and differences. Stat Anal Data Min. 2016;9(5):350-64.
70. Ziv G, Lidor R, Arnon M. Predicting team rankings in basketball: The questionable use of on-court performance statistics. Int J Perf Anal Sport. 2010;10(2):103-14.
71. Zuccolotto P, Manisera M, Sandri M. Big data analytics for modeling scoring probability in basketball: The effect of shooting under high-pressure conditions. Int J Sports Sci Coach. 2018;13(4):569-89.
72. Eugster MJA. Performance profiles based on archetypal athletes. Int J Perf Anal Sport. 2012;12(1):166-87.
73. Gómez M-A, Lorenzo A, Ibañez S-J, Sampaio J. Ball possession effectiveness in men's and women's elite basketball according to situational variables in different game periods. J Sport Sci. 2013;31(14):1578-87.
74. Suárez-Cadenas E, Courel-Ibáñez J. Shooting strategies and effectiveness after offensive rebound and its impact on game result in Euroleague basketball teams. Cuad de Psicol del Deporte. 2017;17(3):217-22.
75. Alfonso JD, Ortega E, Palao JM. Age, participation time and performance in basketball players in Olympic games. Rev Psicol Deporte. 2009;18(suppl.):385-90.
76. Ciampolini V, Nascimento JVd, Ibáñez SJ, Nicolazzi LdO, Camaroto M, Rocha JCS, et al. Offensive technical-tactical analysis on NBA finalist teams: A case study. J Phys Educ. 2018;29(1):e2931.
77. Csataljay G, James N, Hughes M, Dancs H. Performance differences between winning and losing basketball teams during close, balanced and unbalanced quarters. J Hum Sport Exerc. 2012;7(2):356-64.
78. Csataljay G, James N, Hughes M, Dancs H. Effects of defensive pressure on basketball shooting performance. Int J Perf Anal Sport. 2013;13(3):594-601.
79. Csataljay G, James N, Hughes M, Dancs H. Analysis of influencing factors behind offensive rebounding performance in elite basketball. Int J Sports Sci Coach. 2017;12(6):774-81.
80. Ibanez SJ, Mazo A, Nascimento J, Garcia-Rubio J. The relative age effect in under-18 basketball: Effects on performance according to playing position. PLoS One. 2018;13(7):1-11.
81. Zhang S, Lorenzo A, Zhou C, Cui Y, Gonçalves B, Angel Gómez M. Performance profiles and opposition interaction during game-play in elite basketball: Evidences from National Basketball Association. Int J Perf Anal Sport. 2019;19(1):28-48.

82. Choi D-H, Kim S-M, Lee J-W, Suh S-H, So W-Y. Winning factors: How players' positional offensive and defensive skills affect probability of victory in the Korea Basketball League. Int J Sports Sci Coach. 2015;10(2-3):453-9.
83. Mertz J, Hoover DL, Burke JM, Bellar D, Jones LM, Leitzelar B, et al. Ranking the greatest NBA players: A sport metrics analysis. Int J Perf Anal Sport. 2016;16(3):737-59.
84. Bianchi F, Facchinetti T, Zuccolotto P. Role revolution: Towards a new meaning of positions in basketball. Electron J Appl Stat Anal. 2017;10(3):712-34.
85. Bardavío JS, Arroyave VM, González RH, Leri ES, De Ocáriz Granja US. T-patterns initiated with ball screen or one-on-one in basketball. Rev Psicol Deporte. 2017;26(Suppl 1):81-6.
86. Fernández R, Ortega E, Ubal M, Gómez MA, Ibáñez SJ. Descriptive study of the use of defensive factors in the highest division of Chilean basketball (dimayor). Rev Kronos. 2010;9(17):73-80.
87. Gómez MA, Alarcón F, Ortega E. Analysis of shooting effectiveness in elite basketball according to match status. Rev Psicol Deporte. 2015;24(3):37-41.
88. Lamas L, De Rose D, Jr., Santana F, Rostaiser E, Negretti L, Ugrinowitsch C. Space creation dynamics in basketball offence: Validation and evaluation of elite teams. Int J Perf Anal Sport. 2011;11(1):71-84.
89. Pic Aguilar M. Different motor patterns in basketball depending on gender? Cuad Psicol Deporte. 2017;17(3):149-56.
90. Pic M. Performance and home advantage in handball. J Hum Kinet. 2018;63(1):61-71.
91. Marmarinos C, Apostolidis N, Kostopoulos N, Apostolidis A. Efficacy of the 'pick and roll' offense in top level European basketball teams. J Hum Kinet. 2016;50(2):121-9.
92. Remmert H, Chau A-T. Players' decisions within ball screens in elite German men's basketball: Observation of offensive-defensive interactions using a process-orientated state-event model. Int J Perf Anal Sport. 2019;19(1):1-13.
93. Santana FL, Rostaiser E, Sherzer E, Ugrinowitsch C, Barrera J, Lamas L. Space protection dynamics in basketball: Validation and application to the evaluation of offense-defense patterns. Mot Rev de Educ Fis. 2015;21(1):34-44.
94. Wu S, Bornn L. Modeling offensive player movement in professional basketball. Am Stat. 2018;72(1):72-9.
95. Alvarez A, Ortega E, Angel Gomez M, Salado J. Study of the defensive performance indicators in peak performance basketball. Rev Psicol Deporte. 2009;18(suppl.):379-84.
96. Angel GM, Evangelos T, Alberto L. Defensive systems in basketball ball possessions. Int J Perf Anal Sport. 2006;6(1):98-107.
97. Bazanov B, Vohandu P, Haljand R. Trends in offensive team activity in basketball. Educ Phys Train Sport. 2006;2(61):5-11.
98. Calvo JL, García AM, Navandar A. Analysis of mismatch after ball screens in Spanish professional basketball. Int J Perf Anal Sport. 2017;17(4):555-62.
99. Cárdenas D, Piñar M, Llorca-Miralles J, Ortega E, Courel J. Influence of the form of use of space on fastbreak effectiveness in high performance male basketball. J Sport Health Res. 2012;4(2):181-90.
100. Christmann J, Akamphuber M, Muellenbach AL, Guellich A. Crunch time in the NBA - The effectiveness of different play types in the endgame of close matches in professional basketball. Int J Sports Sci Coach. 2018;13(6):1090-9.
101. Ciampolini V, Ibáñez SJ, Nunes ELG, Borgatto AF, Nascimento JVd. Factors associated with basketball field goals made in the 2014 NBA finals. Mot Rev de Educ Fis. 2017;23(4):e1017105.
102. Courel J, Suarez E, Ortega E, Pinar M, Cardenas D. Is the inside pass a performance indicator? Observational analysis of elite basketball teams. Rev Psicol Deporte. 2013;22(1):191-4.

103. Courel-Ibanez J, McRobert AP, Ortega Toro E, Cardenas Velez D. Inside pass predicts ball possession effectiveness in NBA basketball. Int J Perf Anal Sport. 2016;16(2):711-25.
104. Garefis A, Tsitskaris G, Mexas K, Kyriakou D. Comparison of the effectiveness of fast breaks in two high level basketball championships. Int J Perf Anal Sport. 2007;7(3):9-17.
105. George M, Evangelos T, Alexandros K, Athanasios L. The inside game in world basketball. Comparison between European and NBA teams. Int J Perf Anal Sport. 2009;9(2):157-64.
106. Gómez M-Á, Avugos S, Oñoro M-Á, Lorenzo A, Bar-Eli M. Shaq is not alone: Free-throws in the final moments of a basketball game. J Hum Kinet. 2018;62:135-44.
107. Gómez M-Á, Battaglia O, Lorenzo A, Lorenzo J, Jiménez S, Sampaio J. Effectiveness during ball screens in elite basketball games. J Sport Sci. 2015;33(17):1844-52.
108. Hobbs W, Gorman AD, Morgan S, Mooney M, Freeston J. Measuring spatial scoring effectiveness in women's basketball at the 2016 Olympic Games. Int J Perf Anal Sport. 2018;18(6):1037-49.
109. Hobbs W, Morgan S, Gorman AD, Mooney M, Freeston J. Playing unpredictably: Measuring the entropy of ball trajectories in international women's basketball. Int J Perf Anal Sport. 2018;18(1):115-26.
110. Ibanez SJ, Santos JA, Garcia J. Multifactorial analysis of free throw shooting in eliminatory basketball games. Int J Perf Anal Sport. 2015;15(3):897-912.
111. Jiménez-Torres MG, López Gutiérrez CJ. The successful free throw in basketball: How it influences the minute of the game, the scoreboard and be home or visitor team. Cuad Psicol Deporte. 2012;12(2):25-38.
112. Karipidis A, Mavridis G, Tsamourtzis E, Rokka S. The effectiveness of control offense, following an outside game in European championships. Inq Sport Phys Educ. 2010;8(1):99-106.
113. Koutsouridis C, Karamousalidis G, Galazoulas C. The efficacy of "high pick and roll" in relation to the defence's reaction and its effect on the result of the game. Int J Perf Anal Sport. 2018;18(4):554-67.
114. Lamas L, Rostaiser E, Santana F, Tricoli V, Ugrinowitsch C. Diversity and efficiency of space creation dynamics and degree of cooperation among the Paulista basketball teams: Effect of the age group. Rev Bras Educ Fis Esporte. 2011;25(4):693-705.
115. Martinez-Santos R, Martinez-Gutierrez E, Mujika-Garcia M. Temporal logic of free throwing in the Spanish ACB basketball competition. Rev Psicol Deporte. 2017;26:101-7.
116. Nunes H, Iglesias X, Daza G, Irurtia A, Caparrós T, Anguera MT. Influence of pick and roll in attacking game in high-level basketball. Cuad Psicol Deporte. 2016;16(1):129-42.
117. Ribas RL, Navarro RM, Tavares F, Gomez MA. An analysis of the side of rebound in high level basketball games. Int J Perf Anal Sport. 2011;11(2):220-6.
118. Santana F, Fellingham G, Rangel W, Ugrinowitsch C, Lamas L. Assessing basketball offensive structure: The role of concatenations in space creation dynamics. Int J Sports Sci Coach. 2019;14(2):1-11.
119. Vaquera A, Garcia-Tormo JV, Gomez Ruano MA, Morante JC. An exploration of ball screen effectiveness on elite basketball teams. Int J Perf Anal Sport. 2016;16(2):475-85.
120. Courel-Ibanez J, McRobert AP, Ortega Toro E, Cardenas Velez D. Inside game effectiveness in NBA basketball: Analysis of collective interactions. Kinesiology. 2018;50(2):218-27.
121. Conte D, Favero TG, Niederhausen M, Capranica L, Tessitore A. Determinants of the effectiveness of fast break actions in elite and sub-elite Italian men's basketball games. Biol Sport. 2017;34(2):177-83.
122. Kempe M, Grunz A, Memmert D. Detecting tactical patterns in basketball: Comparison of merge self-organising maps and dynamic controlled neural networks. Eur J Sport Sci. 2015;15(4):249-55.

123. Bourbousson J, Deschamps T, Travassos B. From players to teams: Towards a multi-level approach of game constraints in team sports. Int J Sports Sci Coach. 2014;9(6):1393-406.
124. Lopes A, Fonseca S, Lese R, Baca A. Using voronoi diagrams to describe tactical behaviour in invasive team sports: An application in basketball. Cuad Psicol Deporte. 2015;15(1):123-30.
125. Clemente FM, Martins FML, Mendes RS. Technical accuracy it is associated with prominence levels in basketball? J Phys Educ Sport. 2015;15(3):400-6.
126. Spencer K, Griffin M. Do I pass to my friend or the best player? The influence of psychological variables on passing and performance in field hockey. Int J Perf Anal Sport. 2013;13(2):500-9.
127. Lythe J, Kilding AE. The effect of substitution frequency on the physical and technical outputs of strikers during field hockey match play. Int J Perf Anal Sport. 2013;13(3):848-59.
128. Amjad I, Hussain I, Asadullah M. Comparison between long corners and short corners in field hockey. Rawal Med J. 2013;38(4):428-31.
129. Laird P, Sutherland P. Penalty corners in field hockey: A guide to success. Int J Perf Anal Sport. 2003;3(1):19-26.
130. Sunderland C, Bussell C, Atkinson G, Alltree R, Kates M. Patterns of play and goals scored in international standard women's field-hockey. Int J Perf Anal Sport. 2006;6(1):13-29.
131. Ariff M, Norasrudin S, Rahmat A, Shariman I. Passing sequences towards field goals and penalty corners in men's field hockey. J Hum Sport Exerc. 2014;10(2):S638-S47.
132. Park J-C, Choi E-Y, Kim J-E, Lee S-H, Kim J-Y. The effect of foul on the performance during the field hockey game. J Digit Converg. 2018;16(9):489-95.
133. Piñeiro Mosquera R, Molinuevo JS, Román IR. Differences between international men's and women's teams in the strategic action of the penalty corner in field hockey. Int J Perf Anal Sport. 2007;7(3):67-83.
134. Tromp M, Holmes L. The effect of free-hit rule changes on match variables and patterns of play in international standard women's field hockey. Int J Perf Anal Sport. 2011;11(2):376-91.
135. Stöckl M, Morgan S. Visualization and analysis of spatial characteristics of attacks in field hockey. Int J Perf Anal Sport. 2013;13(1):160-78
136. Kim J-E, Lee S-M, Park J-C, Lee H. A study on women's field hockey centrality analysis using social network theory. J Digit Converg. 2018;16(9):437-42.
137. Abdel-Hakim HH. Quantitative analysis of performance indicators of goals scored in the futsal World Cup Thailand 2012. Pamukkale J Sports Sci. 2014;5(1):113-27.
138. Alvurdu S. UEFA futsal Euro 2012: Technical and tactical analysis of Turkish futsal national team group matches. Pamukkale J Sports Sci. 2013;4(4):104-10.
139. da Cunha Voser R, da Silva Cardoso MF, Cícero Moraes J, dos Santos Cunha G, Gomes Voser PE, Lima Morais M. The relationship between chutes to gol and the final result in the futsal World Cup in Thailand in 2012. Rev Bras Futsal Futeb. 2017;9(34):258-64.
140. Gómez MÁ, Moral J, Lago-Peñas C. Multivariate analysis of ball possessions effectiveness in elite futsal. J Sport Sci. 2015;33(20):2173-81.
141. Vilar L, Araújo D, Davids K, Correia V, Esteves PT. Spatial-temporal constraints on decision-making during shooting performance in the team sport of futsal. J Sport Sci. 2013;31(8):840-6.
142. Vilar L, Araújo D, Davids K, Travassos B, Duarte R, Parreira J. Interpersonal coordination tendencies supporting the creation/prevention of goal scoring opportunities in futsal. Eur J Sport Sci. 2014;14(1):28-35.
143. Vicente-Vila P, Lago-Penas C. The goalkeeper influence on ball possession effectiveness in futsal. J Hum Kinet. 2016;51(1):217-24.
144. Garcia-Angulo A, Garcia-Angulo FJ. Analysis of corner kicks in relation to performance in the UEFA Euro futsal 2016. J Sport Health Res. 2018;10(3):403-14.
145. Fonseca S, Milho J, Travassos B, Araújo D. Spatial dynamics of team sports exposed by voronoi diagrams. Hum Mov Sci. 2012;31(6):1652-9.

146. McGuigan K, Hughes M, Martin D. Performance indicators in club level Gaelic football. Int J Perf Anal Sport. 2018;18(5):780-95.
147. Allister A, Byrne PJ, Nulty CD, Jordan S. Game-related statistics which discriminate elite senior Gaelic football teams according to game outcome and final score difference. Int J Perf Anal Sport. 2018;18(4):622-32.
148. Carroll R. Team performance indicators in Gaelic football and opposition effects. Int J Perf Anal Sport. 2013;13(3):703-15.
149. Lynch P, Carroll R. To compare the type of passing in Gaelic football at senior inter-county level historically to modern day. Int J Perf Anal Sport. 2017;17(6):986-95.
150. Bradley J, O'Donoghue P. Counterattacks in elite Gaelic football competition. Int J Perf Anal Sport. 2011;11(1):159-70.
151. Gomes F, Volossovitch A, Ferreira AP. Team timeout calling in handball. Int J Perf Anal Sport. 2014;14(1):98-110.
152. Gutierrez-Aguilar O, Montoya-Fernandez M, Fernandez-Romero JJ, Saavedra-Garcia MA. Analysis of time-out use in handball and its influence on the game performance. Int J Perf Anal Sport. 2016;16(1):1-11.
153. Marczinka Z, Gal A. The chain reaction between the media and sport. The impact of rule changes in handball. Phys Cult Sport Stud Res. 2018;80(1):39-47.
154. Menevşe A, Arslan C. Comparison of the correlation between the reaction time and in-game performance of the elite handball teams. Middle East J Sci Res. 2012;11(4):402-7.
155. Mortimer P, Burt EW. Does momentum exist in elite handball? Int J Perf Anal Sport. 2014;14(3):788-800.
156. Prieto J, Gomez M-A, Volossovitch A, Sampaio J. Effects of team timeouts on the teams' scoring performance in elite handball close games. Kinesiology. 2016;48(1):115-23.
157. Bilge M. Game analysis of Olympic, World and European championships in men's handball. J Hum Kinet. 2012;35:109-18.
158. Daza G, Andres A, Tarrago R. Match statistics as predictors of team's performance in elite competitive handball. Rev Int Cienc Deporte. 2017;13(48):149-61.
159. Debanne T. Effects of game location, quality of opposition and players' exclusions on performance in elite male handball. Rev Int Cienc Deporte. 2018;14(51):71-83.
160. Gomez MA, Lago-Penas C, Viano J, Gonzalez-Garcia I. Effects of game location, team quality and final outcome of game-related statistics in professional handball close games. Kinesiology. 2014;46(2):249-57.
161. Konstantinos NS, Elissavet RN, Panagiotis MG, Ioannis BA, Konstantinos BD. Performance indicators and competition ranking in women's and men's World Handball Championship 2017. J Phys Educ Sport. 2018;18(3):1761-6.
162. Krawczyk P. Technical errors and the venue of the match in handball. Polish J Sport Tour. 2015;22(1):25-9.
163. Teles N, Volossovitch A. Influence of contextual variables on team performance in the last 10 minutes of the handball game. Rev Bras Educ Fis Esporte. 2015;29(2):177-87.
164. Foretic N, Rogulj N, Papic V. Empirical model for evaluating situational efficiency in top level handball. Int J Perf Anal Sport. 2013;13(2):275-93.
165. Gruič I, Vuleta D, Milanovič D. Performance indicators of teams at the 2003 men's world handball championship in Portugal. Kinesiology. 2006;38(2):164-73.
166. Gryko K, Bodasinski S, Bodasinska A, Zielinski J. Offensive and defensive play in handball in a 2-year world championship cycle: Characteristics and tendencies. Polish J Sport Tour. 2018;25(3):10-6.

167. Hatzimanouil D, Giatsis G, Kepesidou M, Kanioglou A, Loizos N. Shot effectiveness by playing position with regard to goalkeeper's efficiency in team handball. J Phys Educ Sport. 2017;17(2):656-62.
168. Milanovic D, Vuleta D, Ohnjec K. Performance indicators of winning and defeated female handball teams in matches of the 2012 Olympic games tournament. J Hum Kinet. 2018;64(1):247-53.
169. Ohnjec K, Vuleta D, Milanovi D, Gruic I. Performance indicators of teams at the 2003 world handball championship for women in Croatia. Kinesiology. 2008;40(1):69-79.
170. Rogulj N. Differences in situation-related indicators of the handball game in relation to the achieved competitive results of teams at 1999 world championship in Egypt. Kinesiology. 2000;32(2):63-74.
171. Gonzalez Ramirez A, Bermudez Pirez SG, Martinez Martin I, Chirosa Rios LJ. Goalkeepers' effectiveness in the ODESUR games and the Pan-American handball championship in 2014. Apunt Educ Fis Deportes. 2017;130(4):95-105.
172. Hansen C, Sanz-Lopez F, Whiteley R, Popovic N, Ahmed HA, Cardinale M. Performance analysis of male handball goalkeepers at the World Handball Championship 2015. Biol Sport. 2017;34(4):393-400.
173. Jimenez-Olmedo JM, Espina-Agullo JJ, Manchado C. Historical analysis of throwing effectiveness in male handball. Retos. 2017;32(2):228-32.
174. Lago-Penas C, Gomez MA, Viano J, Gonzalez-Garcia I, de los Angeles Fernandez-Villarino M. Home advantage in elite handball: The impact of the quality of opposition on team performance. Int J Perf Anal Sport. 2013;13(3):724-33.
175. Meletakos P, Vagenas G, Bayios I. A multivariate assessment of offensive performance indicators in men's handball: Trends and differences in the world championships. Int J Perf Anal Sport. 2011;11(2):284-94.
176. Pori P, Šibila M. Differences in the acyclic activities of the wing players in the team handball matches played with a zone defence 6:0 and 3:2:1. Sport: Revija Za Teoreticna in Prakticna Vprasanja Sporta. 2015;63(1/2):115-20.
177. Saavedra JM, Porgeirsson S, Kristjansdottir H, Chang M, Halldorsson K. Handball game-related statistics in men at Olympic games (2004-2016): Differences and discriminatory power. Retos: Nuevas Tendencias Educ Fis Deporte Recreac. 2017;32(2):260-3.
178. Saavedra JM, Þorgeirsson S, Chang M, Kristjánsdóttir H, García-Hermoso A. Discriminatory power of women's handball game-related statistics at the Olympic games (2004-2016). J Hum Kinet. 2018;62(1):221-9.
179. Skarbalius A, Pukėnas K, Vidūnaitė G. Sport performance profile in men's European modern handball: Discriminant analysis between winners and losers. Educ Phys Train Sport. 2013;90(3):44-54.
180. Skarbalius A, Strielciunas R, Purvys D. The playing peculiarities of Lithuanian men's handball national team in the qualification of world championship XVIII. Educ Phys Train Sport. 2004;3(53):43-9.
181. Valentin LF. Women's handball world championship 2017 case study: European teams versus rest of the participating teams' efficiency. Acta Kinesiol. 2018;12(1):19-23.
182. Valentin LF. Longitudinal study on the effectiveness of the game actions in men's handball top competitions (1998-2016). Kinesiol Slov. 2018;24(2):36-43.
183. García IG. The tactical use of the free-throw in handball. Rev Cienc Deporte. 2015;11(1):39-54.
184. Ohnjec K, Vuleta D, Dizdar D, Milanović D. Structural analysis of counter-attacks performed at the 2010 European handball championship for women. Sport Sci. 2015;8(Suppl 2):69-75.
185. Schrapf N, Tilp M. Action sequence analysis in team handball. J Hum Sport Exerc. 2013;8(3):S615-S21.

186. Silva JA, Garganta J, Janeira MA. Analysis of the teams handball's behavior after entry into ball possession without conceding goal in situations 7 vs 7. Study of the behavior of the victorious and defeated teams, using the sequential analysis. Rev Portuguesa Cienc Desporto. 2013;13(2):57-70.
187. Costa GDCT, Pedrosa GF, Souza NPd, Gemente FRF, Freire AB, Castro HdO. Type of game practiced in handball according to the positions of the attackers: Analysis of the women's world handball championship 2015. Int J Per Anal Spor. 2017;17(3):360-73.
188. Fasold F, Redlich D. Foul or no foul? Effects of permitted fouls on the defence performance in team handball. J Hum Kinet. 2018;63(1):53-9.
189. Pueo B, Espina-Agullo JJ. Relationship between exclusions and final results in European championships, world championships and Olympic games in men's handball 1982-2014. J Phys Educ Sport. 2017;17(3):1158-62.
190. Schrapf N, Alsaied S, Tilp M. Tactical interaction of offensive and defensive teams in team handball analysed by artificial neural networks. Math Comp Model Dyn Syst. 2017;23(4):363-71.
191. Hassan A, Schrapf N, Tilp M. The prediction of action positions in team handball by non-linear hybrid neural networks. Int J Perf Anal Sport. 2017;17(3):293-302.
192. Rodríguez JF, Anguera MT. Game pattern in handball according to the player who occupies the centre back position. Apunt Educ Fis Deportes. 2018(134):110-23.
193. O'Donoghue PG. The effect of rule changes in world series netball: A simulation study. Int J Perf Anal Sport. 2012;12(1):90-100.
194. O'Donoghue P, Mayes A, Edwards KM, Garland J. Performance norms for British National Super League Netball. Int J Sports Sci Coach. 2008;3(4):501-11.
195. Bruce L, Brooks ER, Woods CT. Team and seasonal performance indicator evolution in the ANZ Championship netball league. J Sport Sci. 2018;36(24):2771-7.
196. Croft H, Willcox B, Lamb P. Using performance data to identify styles of play in netball: An alternative to performance indicators. Int J Perf Anal Sport. 2017;17(6):1034-43.
197. Bruce L, Farrow D, Raynor A, May E. Notation analysis of skill expertise differences in netball. Int J Perf Anal Sport. 2009;9(2):245-54.
198. Pulling C, Eldridge D, Lomax J. Centre passes in the UK Netball Super League. Int J Perf Anal Sport. 2016;16(1):389-400.
199. Eaves SJ, Hughes MD, Lamb KL. Assessing the impact of the season and rule changes on specific match and tactical variables in professional rugby league football in the United Kingdom. Int J Perf Anal Sport. 2008;8(3):104-18.
200. Woods CT, Leicht AS, Jones B, Till K. Game-play characteristics differ between the European Super League and the National Rugby League: Implications for coaching and talent recruitment. Int J Sports Sci Coach. 2018;13(6):1171-6.
201. Woods CT, Robertson S, Sinclair WH, Collier NF. Non-metric multidimensional performance indicator scaling reveals seasonal and team dissimilarity within the National Rugby League. J Sci Med Sport. 2018;21(4):410-5.
202. Woods CT, Robertson S, Sinclair WH, Till K, Pearce L, Leicht AS. A comparison of game-play characteristics between elite youth and senior Australian National Rugby League competitions. J Sci Med Sport. 2018;21(6):626-30.
203. Woods CT, Sinclair W, Robertson S. Explaining match outcome and ladder position in the National Rugby League using team performance indicators. J Sci Med Sport. 2017;20(12):1107-11.
204. Parmar N, James N, Hearne G, Jones B. Using principal component analysis to develop performance indicators in professional rugby league. Int J Perf Anal Sport. 2018;18(6):938-49.

205. Parmar N, James N, Hughes M, Jones H, Hearne G. Team performance indicators that predict match outcome and points difference in professional rugby league. Int J Perf Anal Sport. 2017;17(6):1044-56.
206. Kempton T, Kennedy N, Coutts AJ. The expected value of possession in professional rugby league match-play. J Sport Sci. 2016;34(7):645-50.
207. Eaves S, Broad G. A comparative analysis of professional rugby league football playing patterns between Australia and the United Kingdom. Int J Perf Anal Sport. 2007;7(3):54-66.
208. Eaves SJ, Evers AL. The relationship between the 'play the ball' time, post-ruck action and the occurrence of perturbations in professional rugby league football. Int J Perf Anal Sport. 2007;7(3):18-25.
209. Higham DG, Hopkins WG, Pyne DB, Anson JM. Patterns of play associated with success in international rugby sevens. Int J Perf Anal Sport. 2014;14(1):111-22.
210. Higham DG, Hopkins WG, Pyne DB, Anson JM. Relationships between rugby sevens performance indicators and international tournament outcomes. J Quant Anal Sports. 2014;10(1):81-7.
211. Ross A, Gill N, Cronin J, Malcata R. Defensive and attacking performance indicators in rugby sevens. Int J Perf Anal Sport. 2016;16(2):569-80.
212. Barkell JF, O'Connor D, Cotton WG. Characteristics of winning men's and women's sevens rugby teams throughout the knockout cup stages of international tournaments. Int J Perf Anal Sport. 2016;16(2):633-51.
213. Higham DG, Hopkins WG, Pyne DB, Anson JM. Performance indicators related to points scoring and winning in international rugby sevens. J Sport Sci Med. 2014;13(2):358-64.
214. Barkell JF, O'Connor D, Cotton WG. Perturbation effects in men's and women's international sevens. Int J Perf Anal Sport. 2017;17(1-2):17-33.
215. Barkell JF, O'Connor D, Cotton WG. Situational coupling at the ruck and its effects on phase momentum and success in international men's and women's rugby sevens. J Hum Sport Exerc. 2017;12(2):294-306.
216. Barkell JF, Pope A, O'Connor D, Cotton WG. Predictive game patterns in world rugby sevens series games using markov chain analysis. Int J Perf Anal Sport. 2017;17(4):630-41.
217. Jones NM, James N, Mellalieu SD. An objective method for depicting team performance in elite professional rugby union. J Sport Sci. 2008;26(7):691-700.
218. Ortega E, Villarejo D, Palao JM. Differences in game statistics between winning and losing rugby teams in the Six Nations Tournament. J Sport Sci Med. 2009;8(4):523-7.
219. Quarrie KL, Hopkins WG. Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004. J Sport Sci. 2007;25(8):895-903.
220. van Rooyen MK, Noakes TD. Movement time as a predictor of success in the 2003 Rugby World Cup Tournament. Int J Perf Anal Sport. 2006;6(1):30-9.
221. Vaz L, Vasilica I, Kraak W, Arrones LS. Comparison of scoring profile and game related statistics of the two finalist during the different stages of the 2011 Rugby World Cup. Int J Perf Anal Sport. 2015;15(3):967-82.
222. Bishop L, Barnes A. Performance indicators that discriminate winning and losing in the knockout stages of the 2011 Rugby World Cup. Int J Perf Anal Sport. 2013;13(1):149-59.
223. Gaviglio CM, James N, Crewther BT, Kilduff LP, Cook CJ. Relationship between match statistics, game outcome and pre-match hormonal state in professional rugby union. Int J Perf Anal Sport. 2013;13(2):522-34.
224. Hughes A, Barnes A, Churchill SM, Stone JA. Performance indicators that discriminate winning and losing in elite men's and women's rugby union. Int J Perf Anal Sport. 2017;17(4):534-44.
225. Kraak W, Coetzee F, Venter R. Analysis of the general match profile of international rugby union between 2007 and 2013. Int J Perf Anal Sport. 2017;17(3):303-18.

226. Kraak W, Venter R, Coetzee F. Scoring and general match profile of Super Rugby between 2008 and 2013. Int J Perf Anal Sport. 2016;16(2):786-805.
227. Lim E, Lay B, Dawson B, Wallman K, Aanderson S. Development of a player impact ranking matrix in Super 14 rugby union. Int J Perf Anal Sport. 2009;9(3):354-67.
228. Schoeman R, Coetzee D, Schall R. Comparisons of performance indicators between Super Rugby and Currie competition during 2014 season. S Afr J Res Sport Phys Educ Recreat. 2017;39(3):135-44.
229. Schoeman R, Coetzee D, Schall R. Analysis of Super Rugby from 2011 to 2015. Int J Perf Anal Sport. 2017;17(3):190-201.
230. Sella FS, McMaster DT, Serpiello FR, La Torre A. Match analysis in rugby union: Performance indicators of rugby championship and Super Rugby teams. J Sport Med Phys Fit. 2018;59(8):1306-10.
231. Vahed Y, Kraak W, Venter R. The effect of the law changes on time variables of the South African Currie Cup Tournament during 2007 and 2013. Int J Perf Anal Sport. 2014;14(3):866-83.
232. Vahed Y, Kraak W, Venter R. Changes on the match profile of the South African Currie Cup tournament during 2007 and 2013. Int J Sports Sci Coach. 2016;11(1):85-97.
233. van den Berg P, Malan DDJ. The effect of experimental law variations on the Super 14 Rugby Union tournaments. Afr J Phys Health Educ Recreat Dance. 2012;18(3):476-86.
234. van den Berg PH, Malan DDJ. Match analysis of the 2006 Super 14 Rugby Union tournament. Afr J Phys Health Educ Recreat Dance. 2010;16(4):580-93.
235. van Rooyen MK, Lambert MI, Noakes TD. A retrospective analysis of the IRB statistics and video analysis of match play to explain the performance of four teams in the 2003 Rugby World Cup. Int J Perf Anal Sport. 2006;6(1):57-72.
236. van Rooyen MK, Lombard C, Noakes TD. Playing demands of sevens rugby during the 2005 Rugby World Cup Sevens Tournament. Int J Perf Anal Sport. 2008;8(2):114-23.
237. Vaz L, Carreras D, Kraak W. Analysis of the effect of alternating home and away field advantage during the Six Nations Rugby Championship. Int J Perf Anal Sport. 2012;12(3):593-607.
238. Vaz L, Mouchet A, Carreras D, Morente H. The importance of rugby game-related statistics to discriminate winners and losers at the elite level competitions in close and balanced games. Int J Perf Anal Sport. 2011;11(1):130-41.
239. Vaz L, Van Rooyen M, Sampaio J. Rugby game-related statistics that discriminate between winning and losing teams in IRB and Super twelve close games. J Sport Sci Med. 2010;9(1):51-5.
240. Vaz LMT. Match and result actions that best discriminate wins and losses in Super Rugby's balanced "rugby" games. Rev Bras Educ Fis Esporte. 2012;26(1):111-7.
241. Villarejo D, Ortega E, Gomez M-A, Palao J-M. Design, validation, and reliability of an observational instrument for ball possessions in rugby union. Int J Perf Anal Sport. 2014;14(3):955-67.
242. Villarejo D, Palao JM, Ortega E. Differences in technical and tactical indicators of performance between winners and losers in the women Rugby World Cup 2010. Cuad Psicol Deporte. 2016;16(1):269-74.
243. Watson N, Durbach I, Hendricks S, Stewart T. On the validity of team performance indicators in rugby union. Int J Perf Anal Sport. 2017;17(4):609-21.
244. Bennett M, Bezodis N, Shearer DA, Locke D, Kilduff LP. Descriptive conversion of performance indicators in rugby union. J Sci Med Sport. 2019;22(3):330-4.
245. Bremner S, Robinson G, Williams MD. A retrospective evaluation of team performance indicators in rugby union. Int J Perf Anal Sport. 2013;13(2):461-73.

246. Lim E, Lay B, Dawson B, Wallman K, Anderson S. Predicting try scoring in super 14 rugby union - The development of a superior attacking team scoring system. Int J Perf Anal Sport. 2011;11(3):464-75.
247. Quarrie KL, Hopkins WG. Evaluation of goal kicking performance in international rugby union matches. J Sci Med Sport. 2015;18(2):195-8.
248. Croft H, Lamb P, Middlemas S. The application of self-organising maps to performance analysis data in rugby union. Int J Perf Anal Sport. 2015;15(3):1037-46.
249. Bracewell P. Monitoring meaningful rugby ratings. J Sport Sci. 2003;21(8):611-20.
250. Hughes M, Smyth G. Profiling half-back play in rugby union and the impact of substitutions. J Hum Sport Exerc. 2018;13(4):940-62.
251. James N, Mellalieu SD, Jones NM. The development of position-specific performance indicators in professional rugby union. J Sport Sci. 2005;23(1):63-72.
252. van Rooyen MK, Noakes TD. An analysis of the movements, both duration and field location, of 4 teams in the 2003 Rugby World Cup. Int J Perf Anal Sport. 2006;6(1):40-56.
253. Villarejo D, Gómez MA, Palao JM, Ortega E. Differences in game-related statistics between home and away international rugby teams. Rev Kronos. 2012;11(2):37-44.
254. Villarejo D, Palao JM, Ortega E, Gomez-Ruano MA, Kraak W. Match-related statistics discriminating between playing positions during the men's 2011 Rugby World Cup. Int J Perf Anal Sport. 2015;15(1):97-111.
255. Villarejo D, Palao JM, Toro EO. Match profiles for establishing position specific rehabilitation for rugby union players. Int J Perf Anal Sport. 2013;13(2):567-71.
256. Calder JM, Durbach IN. Decision support for evaluating player performance in rugby union. Int J Sports Sci Coach. 2015;10(1):21-37.
257. van Rooyen MK, Diedrick E, Noakes TD. Ruck frequency as a predictor of success in the 2007 Rugby World Cup Tournament. Int J Perf Anal Sport. 2010;10(1):33-46.
258. Williams JJ, James N, Hughes M. Performance analysis and cheating in sport - A model for discussion. Int J Perf Anal Sport. 2011;11(1):121-9.
259. Diedrick E, van Rooyen M. Line break situations in international rugby. Int J Perf Anal Sport. 2011;11(3):522-34.
260. Evans L, O'Donoghue P. The effectiveness of the chop tackle in elite and semi-professional rugby union. Int J Perf Anal Sport. 2013;13(3):602-11.
261. Franken L, van Vuuren H, Kraak W, Vaz L. Investigation and comparison of lineouts during the 2013 the Rugby Championship and Six-Nations Competition. Int J Perf Anal Sport. 2017;17(1-2):65-76.
262. Kraak WJ, Welman KE. Ruck-play as performance indicator during the 2010 Six Nations Championship. Int J Sports Sci Coach. 2014;9(3):525-38.
263. Migdalski AH, Stone JA. Investigating lineout performance between the top and bottom four English Premiership rugby union teams in the 2016/17 season. Int J Perf Anal Sport. 2019;19(1):131-41.
264. Pulling C, Stenning M. Offloads in rugby union: Northern and southern hemisphere international teams. Int J Perf Anal Sport. 2015;15(1):217-28.
265. Sasaki K, Furukawa T, Murakami J, Shimozono H, Nagamatsu M, Miyao M, et al. Scoring profiles and defense performance analysis in rugby union. Int J Perf Anal Sport. 2007;7(3):46-53.
266. van Rooyen MK. A statistical analysis of tackling performance during international rugby union matches from 2011. Int J Perf Anal Sport. 2012;12(3):517-30.
267. Wheeler KW, Mills D, Lyons K, Harrinton W. Effective defensive strategies at the ruck contest in rugby union. Int J Sports Sci Coach. 2013;8(3):481-91.

268. Lamb P, Croft H. Visualizing rugby game styles using self-organizing maps. IEEE Comput Graph Appl. 2016;36(6):11-5.
269. Alp I, Ozsoy VS. Two stage approach for the performances of teams in football using data envelopment analysis. Gazi Un J Sci. 2017;30(3):195-208.
270. de Castro Silveira JF. Effectiveness and offensive performance analysis of the football's World Cup: Russia 2018. Rev Bras Futsal Futeb. 2018;10(41):785-94.
271. Garcia-Rubio J, Angel Gomez M, Lago-Penas C, Ibanez SJ. Effect of match venue, scoring first and quality of opposition on match outcome in the UEFA Champions League. Int J Perf Anal Sport. 2015;15(2):527-39.
272. Garratt K, Murphy A, Bower R. Passing and goal scoring characteristics in Australian A-League football. Int J Perf Anal Sport. 2017;17(1-2):77-85.
273. Gomez M-A, Lago-Penas C, Owen AL. The influence of substitutions on elite soccer teams' performance. Int J Perf Anal Sport. 2016;16(2):553-68.
274. Kempe M, Memmert D. "Good, better, creative": The influence of creativity on goal scoring in elite soccer. J Sport Sci. 2018;36(21):2419-23.
275. Lago-Penas C, Dellal A. Ball possession strategies in elite soccer according to the evolution of the match-score: The influence of situational variables. J Hum Kinet. 2010;25(1):93-100.
276. Lago-Penas C, Gomez M-A, Pollard R. Home advantage in elite soccer matches. A transient effect? Int J Perf Anal Sport. 2017;17(1-2):86-95.
277. Lago-Penas C, Gomez-Ruano M, Megias-Navarro D, Pollard R. Home advantage in football: Examining the effect of scoring first on match outcome in the five major European leagues. Int J Perf Anal Sport. 2016;16(2):411-21.
278. Liu H, Gomez M-Á, Lago-Peñas C, Sampaio J. Match statistics related to winning in the group stage of 2014 Brazil FIFA World Cup. J Sport Sci. 2015;33(12):1205-13.
279. Mao L, Peng Z, Liu H, Gomez M-A. Identifying keys to win in the Chinese professional soccer league. Int J Perf Anal Sport. 2016;16(3):935-47.
280. Oliveira P, Clemente FM. Network properties and performance variables and their relationships with distance covered during elite soccer games. J Phys Educ Sport. 2018;18(Suppl 2):1045-9.
281. Pratas JM, Volossovitch A, Carita AI. The effect of performance indicators on the time the first goal is scored in football matches. Int J Perf Anal Sport. 2016;16(1):347-54.
282. Shafizadeh M, Sproule J, Gray S. The emergence of coordinative structures during offensive movement for goal-scoring in soccer. Int J Perf Anal Sport. 2013;13(3):612-23.
283. Shulyatyev VM, Ivanov VV, Dugbley AD, Potapov DA, Soparev AA. English versus Russian football premier-league competitive performance analysis factoring in game positions and field control zones. Teor Prak Fiz Kult. 2019;2019(1):78-80.
284. Szwarc A. Effectiveness of Brazilian and German teams and the teams defeated by them during the 17th FIFA World Cup. Kinesiology. 2004;36(1):83-9.
285. Szwarc A. Search for determinants of effective play in soccer on the basis of observation of the best European teams. Phys Educ Sport. 2004;48(1):53-64.
286. Szwarc A. Differences in effectiveness in playing soccer among teams with the highest levels of sports mastery. Phys Educ Sport. 2004;48(2):141-56.
287. Armatas V, Yiannakos A, Sileloglou P. Relationship between time and goal scoring in soccer games: Analysis of three world cups. Int J Perf Anal Sport. 2007;7(2):48-58.
288. Barisic V, Dizdar D, Basic D. Importance of key passes in football based on final outcome of the match and league system of competition. Acta Kinesiol. 2016;10(Suppl 1):94-6.
289. Basic D, Barisic V, Dizdar D. Importance of assisting in football considering the final outcome of the match and league competition system. Acta Kinesiol. 2016;10(Suppl 1):91-3.
290. Basic D, Dizdar D, Jozak R. Analysis of crosses in the Croatian First Football League. Acta Kinesiol. 2016;10(2):52-5.

291. Bašić D, Tomaško J. The importance of ball throw-in in football. Sport Sci. 2017;10(1):86-8.
292. Bezerra MF, Gramacho TG. COPA Libertadores da America 2017 statistics: An analysis of scouts correlation of final phase games. Podium Sport Leis Tour Review. 2018;7(1):161-77.
293. Bostanci O, Mayda MH, Ceylan L, Kaplan A, Satici A, Yazici OF. 2016 UEFA European Championship: Pass and shot association. J Hum Sport Exerc. 2018;13(2):319-27.
294. Cambre Añon I, Lizana CJR, Calazans E, MacHado JC, Da Costa IT, Scaglia AJ. Performance of Barcelona's team and their opponents in the finals matches of the Champions League and the FIFA Club World Cup 2010. Rev Andal Med Deporte. 2014;7(1):13-20.
295. Carmichael F, Thomas D. Home-field effect and team performance evidence from English premiership football. J Sports Econom. 2005;6(3):264-81.
296. Castellano J. Relationship between performance indicators and the success in professional football. Rev Iberoam Psicol Ejerc Deporte. 2018;13(1):41-9.
297. Castellano J, Casamichana D. Same players with different coaches, can they play in different way to optimize performance in professional football? Sport Tk-Rev Euroam Cienc Deporte. 2016;5(2):133-40.
298. Castellano J, Casamichana D, Lago C. The use of match statistics that discriminate between successful and unsuccessful soccer teams. J Hum Kinet. 2012;31(1):139-47.
299. Clemente F, Couceiro M, Martins FML, Mendes R. Team's performance on FIFA U17 World Cup 2011: Study based on notational analysis. J Phys Educ Sport. 2012;12(1):13-7.
300. Collet C. The possession game? A comparative analysis of ball retention and team success in European and international football, 2007–2010. J Sport Sci. 2013;31(2):123-36.
301. Crnjac D, Dizdar D, Basic D. Importance of penalty kicks in football considering final outcome of the match and league system of competition. Acta Kinesiol. 2016;10(2):7-9.
302. da Costa YP, Marques Junior NK, Soares da Silva EL, Batista GR. Comparison between the numbers of goals achieved in the Brazilian Football Championship 2017 in game time function. Rev Bras Futsal Futeb. 2019;11(43):203-7.
303. de Oliveira Silva JV, Praca GM, Alves da Silva CJ, Greco PJ. Relationship between ball possession and effectiveness in offensive processes in football. Rev Bras Futsal Futeb. 2016;8(29):161-5.
304. de Souza e Silva A, de Oliveira JJ, Rosa Junior NA, Silva Vilela Ribeiro AG, de Oliveira Silva JA, Baganha RJ, et al. Technical indicators of the winning and losing teams of the Champions League 2014/2015. Rev Bras Futsal Futeb. 2018;10(37):179-85.
305. DeFreitas R. Do deceptive and disguised movement behaviours exist in actual soccer match play and does their use indicate elite performance? Int J Perf Anal Sport. 2015;15(3):1047-64.
306. Delgado-Bordonau JL, Domenech-Monforte C, Guzman JF, Mendez-Villanueva A. Offensive and defensive team performance: Relation to successful and unsuccessful participation in the 2010 Soccer World Cup. J Hum Sport Exerc. 2013;8(4):894-904.
307. Dizdar D, Basic D, Barisic V. Differences between the place of the match and ball possession in football league. Acta Kinesiol. 2016;10(Suppl 1):84-6.
308. Dizdar D, Jozak R, Basic D. The importance of offense corner kicks in football with regard to final outcome of the match and league system of competition. Acta Kinesiol. 2016;10(2):56-9.
309. Evangelos B, Aristotelis G, Ioannis G, Stergios K, Foteini A. Winners and losers in top level soccer. How do they differ? J Phys Educ Sport. 2014;14(3):398-405.
310. Evangelos B, Eleftherios M, Aris S, Ioannis G, Aristotelis G, Antonios S. Offense and defense statistical indicators that determine the Greek Superleague teams placement on the table 2011 - 12. J Phys Educ Sport. 2013;13(3):338-47.
311. Evangelos B, Gioldasis A, Ioannis G, Georgia A. Relationship between time and goal scoring of European soccer teams with different league ranking. J Hum Sport Exerc. 2018;13(3):518-28.

312. Filetti C, Ruscello B, D'Ttavio S, Fanelli V. A study of relationships among technical, tactical, physical parameters and final outcomes in elite soccer matches as analyzed by a semiautomatic video tracking system. Percept Mot Skills. 2017;124(3):601-20.
313. Flores FS, dos Santos DL, Carlson GR, Gelain EZ. What can coaches do? The relationship between substitution and results of professional football matches. Rev Bras Futsal Futeb. 2019;11(43):215-22.
314. Guedes JC, Machado FS. Changing rewards in contests: Has the three-point rule brought more offense to soccer? Empir Econ. 2002;27(4):607-30.
315. Gurkan O, Munyrodlu S. Technical and tactical analyses of matches in European Football Championship 2016. J Phys Educ Sports Sci. 2018;16(3):101-8.
316. Harrop K, Nevill A. Performance indicators that predict success in an English professional League One soccer team. Int J Perf Anal Sport. 2014;14(3):907-20.
317. Hongyou L, Gómez MA, Lago-Peñas C, Arias-Estero J, Stefani R. Match performance profiles of goalkeepers of elite football teams. Int J Sports Sci Coach. 2015;10(4):669-82.
318. Janković A, Leontijević B, Pašić M, Jelušić V. Influence of certain tactical attacking patterns on the result achieved by the teams participants of the 2010 FIFA world cup in South Africa. Phys Cult. 2011;65(1):34-45.
319. Kautzner Marques Junior N. World cup of 2014: Statistics of the best four teams. Rev Bras Futsal Futeb. 2015;7(23):80-94.
320. Kite CS, Nevill A. The predictors and determinants of inter-seasonal success in a professional soccer team. J Hum Kinet. 2017;58(1):157-67.
321. Konefal M, Chmura P, Zacharko M, Chmura J, Rokita A, Andrzejewski M. Match outcome vs match status and frequency of selected technical activities of soccer players during UEFA Euro 2016. Int J Perf Anal Sport. 2018;18(4):568-81.
322. Lago-Ballesteros J, Lago-Penas C. Performance in team sports: Identifying the keys to success in soccer. J Hum Kinet. 2010;25(1):85-91.
323. Lago-Penas C, Gomez-Lopez M. How important is it to score a goal? The influence of the scoreline on match performance in elite soccer. Percept Mot Skills. 2014;119(3):774-84.
324. Lago-Penas C, Lago-Ballesteros J. Game location and team quality effects on performance profiles in professional soccer. J Sport Sci Med. 2011;10(3):465-71.
325. Lago-Penas C, Lago-Ballesteros J, Dellal A, Gomez M. Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. J Sport Sci Med. 2010;9(2):288-93
326. Lago-Penas C, Lago-Ballesteros J, Rey E. Differences in performance indicators between winning and losing teams in the UEFA Champions League. J Hum Kinet. 2011;27(1):137-48.
327. Lames M. Chance involvement in goal scoring in football - An empirical approach. Ger J Exerc Sport Res. 2018;48(2):278-86.
328. Link D, Hoernig M. Individual ball possession in soccer. PLoS One. 2017;12(7):1-15.
329. Martinez Martinez FD, Gonzalez-Garcia H. Analysis of goals in European football and the most influential part in final standings. Rev Cienc Deporte. 2018;14(2):89-98.
330. Mitrotasios M. Differences in performance indicators between successful and unsuccessful teams in UEFA-EURO 2012. Biol Exerc. 2018;14(1):11-22.
331. Pappalardo L, Cintia P. Quantifying the relation between performance and success in soccer. Adv Complex Syst. 2018;21(3-4):1-29.
332. Pratas JM, Volossovitch A, Carita AI. Analysis of scoring sequences in matches of the Portuguese Premier League. J Hum Kinet. 2018;64(1):255-63.
333. Redwood-Brown A. Passing patterns before and after goal scoring in FA Premier League Soccer. Int J Perf Anal Sport. 2008;8(3):172-82.

334. Ruiz-Ruiz C, Fradua L, Fernández-García Á, Zubillaga A. Analysis of entries into the penalty area as a performance indicator in soccer. Eur J Sport Sci. 2013;13(3):241-8.
335. Shafizadeh M, Taylor M, Lago Penas C. Performance consistency of international soccer teams in Euro 2012: A time series analysis. J Hum Kinet. 2013;38(1):213-26.
336. Shin M-S. Comparisons of team performance analysis between EURO 2008 semi-finalists and South Korean teams in soccer. Korean J Phys Educ. 2009;48(2):475-82.
337. Soroka A. Trends in the gameplay of European football players. Balt J Health Phys Act. 2014;6(4):267-72.
338. Taylor JB, Mellalieu SD, James N, Shearer DA. The influence of match location, quality of opposition, and match status on technical performance in professional association football. J Sport Sci. 2008;26(9):885-95.
339. Vales A, Areces A, Blanco H, Arce C. Design and application of a multidimensional battery of performance indicators for evaluating competitive performance in top-level football. Rev Int Cienc Deporte. 2011;7(23):103-12.
340. Vales Vazquez A, Blanco Pita H, Areces Gayo A, Arce Fernandez C. Performance profiles of winning and losing team participating in the 2010 FIFA World Cup in South Africa. Rev Psicol Deporte. 2015;24(1):111-8.
341. Yang G, Leicht AS, Lago C, Gomez M-A. Key team physical and technical performance indicators indicative of team quality in the soccer Chinese super league. Res Sports Med. 2018;26(2):158-67.
342. Yue Z, Broich H, Mester J. Statistical analysis for the soccer matches of the first Bundesliga. Int J Sports Sci Coach. 2014;9(3):553-60.
343. Aquino R, Manechini JPV, Bedo BLS, Puggina EF, Garganta J. Effects of match situational variables on possession: The case of England Premier League season 2015/16. Mot Rev Educ Fis. 2017;23(3):e101794.
344. Barron D, Ball G, Robins M, Sunderland C. Artificial neural networks and player recruitment in professional soccer. Plos One. 2018;13(10):e0205818.
345. Caballero P, Garcia-Rubio J, Jose Ibanez S. Influence of situational variables on the U'18 soccer performance analysis. Retos: Nuevas Tendencias Educ Fis Deporte Recrea. 2017;32(1):224-7.
346. Carpita M, Ciavolino E, Pasca P. Exploring and modelling team performances of the Kaggle European Soccer database. Stat Modelling. 2019;19(1):74-101.
347. de Oliveira BM, Dias DF, Alves AL, Ferreira JC, Mezencio B, Soncin R. Scout analysis models for football based on the 2014 World Cup. Rev Bras Futsal Futeb. 2015;7(26):413-8.
348. Goldner K. A markov model of football: Using stochastic processes to model a football drive. J Quant Anal Sports. 2012;8(1):1-16.
349. Ibáñez SJ, Pérez-Goye JA, Courel-Ibáñez J, García-Rubio J. The impact of scoring first on match outcome in women's professional football. Int J Perf Anal Sport. 2018;18(2):318-26.
350. Kim JH, Park J, Ro G-T, Lee Won-Hi. The development of soccer game win lost prediction model using neural network analysis - FIFA world cup 2006 Germany. Korean J Sport Sci. 2007;18(4):54-63.
351. Kobayashi G, Hatakeyama H, Ota K, Nakada Y, Kaburagi T, Matsumoto T. Predicting viewer-perceived activity/dominance in soccer games with stick-breaking HMM using data from a fixed set of cameras. Multimed Tools Appl. 2016;75(6):3081-119.
352. Nakamura LR, Cerqueira PHR, Ramires TG, Pescim RR, Rigby RA, Stasinopoulos DM. A new continuous distribution on the unit interval applied to modelling the points ratio of football teams. J Appl Stat. 2019;46(3):416-31.
353. Neuman Y, Israeli N, Vilenchik D, Cohen Y. The adaptive behavior of a soccer team: An entropy-based analysis. Entropy. 2018;20(10):1-12.

354. Principe V, Gavião LO, Henriques R, Lobo V, Lima GBA, Sant'anna AP. Multicriteria analysis of football match performances: Composition of probabilistic preferences applied to the English Premier League 2015/16. Pesqui Operacional. 2017;37(2):333-63.
355. Thomas C, Fellingham G, Vehrs P. Development of a notational analysis system for selected soccer skills of a women's college team. Meas Phys Educ Exerc Sci. 2009;13(2):108-21.
356. Wunderlich F, Memmert D. The betting odds rating system: Using soccer forecasts to forecast soccer. PloS One. 2018;13(6):1-18.
357. Zambom-Ferraresi F, Rios V, Lera-Lopez F. Determinants of sport performance in European football: What can we learn from the data? Decis Support Syst. 2018;114(1):18-28.
358. Adambekov Y. Principal factors defining success of technical-tactical actions of elite football team. Educ Phys Train Sport. 2014;92(1):3-8.
359. Choi H, Hyen J-W. The clusters of performances based on the official data for the soccer World Cup. Korean J Meas Eval Phys Educ Sport Sci. 2018;20(4):165-74.
360. Stockl M, Plueck D, Lames M. Modelling game sports as complex systems - Application of recurrence analysis to golf and soccer. Math Comput Model Dyn Syst. 2017;23(4):399-415.
361. Gama J, Dias G, Couceiro M, Passos P, Davids K, Ribeiro J. An ecological dynamics rationale to explain home advantage in professional football. Int J Mod Phys C. 2016;27(9):1-15.
362. Oliveira R, Dias G, Vaz V, Gama J. Influence, interaction and performance of key player in football match. Rev Bras Futsal Futeb. 2017;9(33):170-9.
363. Park Y-S, Choi M-S, Bang S-Y, Park J-K. Analysis of shots on target and goals scored in soccer matches: Implications for coaching and training goalkeepers. S Afr J Res Sport Phys Educ Recreat. 2016;38(1):123-37.
364. Shafizadeh M, Lago-Penas C, Gridley A, Platt GK. Temporal analysis of losing possession of the ball leading to conceding a goal: A study of the incidence of perturbation in soccer. Int J Sports Sci Coach. 2014;9(4):627-36.
365. Yi Q, Jia H, Liu H, Angel Gomez M. Technical demands of different playing positions in the UEFA Champions League. Int J Perf Anal Sport. 2018;18(6):926-37.
366. Casal CA, Maneiro R, Arda T, Mari FJ, Losada JL. Possession zone as a performance indicator in football. The game of the best teams. Front Psychol. 2017;8(1):1-11.
367. Clemente F, Couceiro M, Martins FML, Mendes R. Team's performance on FIFA U17 World Cup 2011: Study based on notational analysis. J Phys Educ Sport. 2012;12(1):13-7.
368. de Baranda PS, Adán L, García-Angulo A, Gómez-López M, Nikolic B, Ortega-Toro E. Differences in the offensive and defensive actions of the goalkeepers at women's FIFA World Cup 2011. Front Psychol. 2019;10(2):1-10.
369. Dufour M, Phillips J, Ernwein V. What makes the difference? Analysis of the 2014 World Cup. J Hum Sport Exerc. 2017;12(3):616-29.
370. Gómez MA, Gómez-Lopez M, Lago C, Sampaio J. Effects of game location and final outcome on game-related statistics in each zone of the pitch in professional football. Eur J Sport Sci. 2012;12(5):393-8.
371. Hong S-J. The development of performance determinants criteria for evaluating positional soccer player. Korean J Sport Sci. 2010;21(2):1172-82.
372. Javani M, Hamedinia M, Khodaei K. Technical performance analysis of Iran Premier League soccer players in 2012-2013 season. Pedagog Psych Med-Bio Probl Phys Train Sports. 2015;19(10):77-81.
373. Kempe M, Vogelbein M, Nopp S. The cream of the crop: Analysing FIFA World Cup 2014 and Germany's title run. J Hum Sport Exerc. 2016;11(1):42-52.
374. Leontijević B, Janković A, Tomić L. Attacking performance profile of football teams in different national leagues according to UEFA rankings for club competitions. Ser Phys Educ Sport. 2018;16(4):697-708.

375. Liu H, Gómez M-A, Gonçalves B, Sampaio J. Technical performance and match-to-match variation in elite football teams. J Sport Sci. 2016;34(6):509-18.
376. Michailidis Y, Michailidis C, Primpa E. Analysis of goals scored in European Championship 2012. J Hum Sport Exerc. 2013;8(2):S367-S75.
377. O'Donoghue P, Papadimitriou K, Gourgoulis V, Haralambis K. Statistical methods in performance analysis: An example from international soccer. Int J Perf Anal Sport. 2012;12(1):144-55.
378. Redwood-Brown A, Bussell C, Bharaj HS. The impact of different standards of opponents on observed player performance in the English Premier League. J Hum Sport Exerc. 2012;7(2):341-55.
379. Ridgewell A. Passing patterns before and after scoring in the 2010 FIFA World Cup. Int J Perf Anal Sport. 2011;11(3):562-74.
380. Sgro F, Aiello F, Casella A, Lipoma M. Offensive strategies in the European Football Championship 2012. Percept Mot Skills. 2016;123(3):792-809.
381. Sgro F, Aiello F, Casella A, Lipoma M. The effects of match-playing aspects and situational variables on achieving score-box possessions in Euro 2012 Football Championship. J Hum Sport Exerc. 2017;12(1):58-72.
382. Sgro F, Barresi M, Lipoma M. The analysis of discriminant factors related to team match performances in the 2012 European Football Championship. J Phys Educ Sport. 2015;15(3):460-5.
383. Szwarc A, Kromke K, Radziminski L, Jastrzebski Z. Efficiency of 1-on-1 play situations for high-level soccer players during the World and European championships in relation to position on the pitch and match time. Int J Sports Sci Coach. 2017;12(4):495-503.
384. Tenga A, Mortensholm A, O'Donoghue P. Opposition interaction in creating penetration during match play in elite soccer: Evidence from UEFA champions league matches. Int J Perf Anal Sport. 2017;17(5):802-12.
385. Turner B, Sayers M. The influence of transition speed on event outcomes in a high performance football team. Int J Perf Anal Sport. 2010;10(3):207-20.
386. Volpi Braz T, Reolon Marcelino V. Ball possession maintenance modeling in games of the FIFA World Cup 2010. Rev Bras Futsal Futeb. 2013;5(16):90-8.
387. Volpi Braz T, Reolon Marcelino V. Analysis of ball possession in selections of different continents at the FIFA World Cup 2010. Rev Bras Futsal Futeb. 2014;6(21):234-42.
388. Adams D, Morgans R, Sacramento J, Morgan S, Williams MD. Successful short passing frequency of defenders differentiates between top and bottom four English Premier League teams. Int J Perf Anal Sport. 2013;13(3):653-68.
389. Brooks J, Kerr M, Guttag J. Using machine learning to draw inferences from pass location data in soccer. Stat Anal Data Min. 2016;9(5):338-49.
390. Cakmak A, Uzun A, Delibas E. Computational modeling of pass effectiveness in soccer. Adv Complex Syst. 2018;21(3-4):1-28.
391. Chassy P, Malone JJ, Clark DPA. A mathematical model of self-organisation in football. Int J Perf Anal Sport. 2018;18(2):217-28.
392. Lago C. The influence of match location, quality of opposition, and match status on possession strategies in professional association football. J Sport Sci. 2009;27(13):1463-9.
393. Peñas CL, Martínez LC, Lago ED, Acero RM, Vargas FS-L. The influence of match location, the quality of opposition and match status on possession in professional football. Apunt Educ Fis Esports. 2010;102(4):78-86.
394. Pollard R, Reep C. Measuring the effectiveness of playing strategies at soccer. J R Stat Soc Ser D Stat. 1997;46(4):541-50.

395. Couceiro MS, Clemente FM, Martins FML, Machado JAT. Dynamical stability and predictability of football players: The study of one match. Entropy. 2014;16(2):645-74.
396. Moura FA, Santana JE, Vieira NA, Pereira Santiago PR, Cunha SA. Analysis of soccer players' positional variability during the 2012 UEFA European Championship: A case study. J Hum Kinet. 2015;47(1):225-36.
397. Borrie A, Jonsson GK, Magnusson MS. Temporal pattern analysis and its applicability in sport: An explanation and exemplar data. J Sport Sci. 2002;20(10):845-52.
398. Cavalera C, Barbara D, Elia M, Jonsson GK, Zurloni V, Anguera MT. T-pattern analysis in soccer games: Relationship between time and attack actions. Cuad Psicol Deporte. 2015;15(1):41-50.
399. De Baranda PS, Ortega E, Palao JM. Analysis of goalkeepers' defence in the World Cup in Korea and Japan in 2002. Eur J Sport Sci. 2008;8(3):127-34.
400. Gómez M, Alvaro J, Barriopedro M. Behaviour patterns of finishing plays in female and male soccer. Rev Kronos. 2009;8(15):5-24.
401. Gonzalez-Rodenas J, Lopez Bondia I, Calabuig Moreno F, Aranda Malaves R. Tactical indicators associated with the creation of scoring opportunities in professional soccer. Cult Cienc Deporte. 2015;10(30):215-25.
402. Hughes M, Franks I. Analysis of passing sequences, shots and goals in soccer. J Sport Sci. 2005;23(5):509-14.
403. Mitschke C, Milani TL. Soccer: Detailed analysis of played passes in the UEFA Euro 2012. Int J Sports Sci Coach. 2014;9(5):1019-31.
404. Paixao P, Sampaio J, Almeida CH, Duarte R. How does match status affects the passing sequences of top-level European soccer teams? Int J Perf Anal Sport. 2015;15(1):229-40.
405. Palao JM, López-Montero M, López-Botella M. Relationship between efficacy, laterality of foot strike, and shot zone of the penalty in relation to competition level in soccer. Rev Int Cienc Deporte. 2010;6(19):154-65.
406. Pulling C, Eldridge D, Ringshall E, Robins MT. Analysis of crossing at the 2014 FIFA World Cup. Int J Perf Anal Sport. 2018;18(4):657-77.
407. Rafael MdC, Antonio N, Asier Z, Fradua L. Influence of tactical variables on attacking actions in elite soccer. Kinesiol Slov. 2017;23(3):32-8.
408. Smith RA, Lyons K. A strategic analysis of goals scored in open play in four FIFA World Cup football championships between 2002 and 2014. Int J Sports Sci Coach. 2017;12(3):398-403.
409. Caro O, Caro-Munoz A. Approach to the offensive game model in football through the goal analysis in professional football. J Sport Health Res. 2016;8(1):1-11.
410. Casal CA, Maneiro R, Arda T, Losada JL, Rial A. Effectiveness of indirect free kicks in elite soccer. Int J Perf Anal Sport. 2014;14(3):744-60.
411. Casal CA, Maneiro R, Arda T, Losada JL, Rial A. Analysis of corner kick success in elite football. Int J Perf Anal Sport. 2015;15(2):430-51.
412. Castelão DP, Garganta J, Afonso J, Da Costa IT. Sequential analysis of attacking behaviors performed by top-level national soccer teams. Rev Bras Cienc Esporte. 2015;37(3):230-6.
413. Dalton K, Guillon M, Naroo SA. An analysis of penalty kicks in elite football post 1997. Int J Sports Sci Coach. 2015;10(5):815-27.
414. De Baranda PS, Lopez-Riquelme D. Analysis of corner kicks in relation to match status in the 2006 World Cup. Eur J Sport Sci. 2012;12(2):121-9.
415. Diana B, Zurloni V, Elia M, Cavalera CM, Jonsson GK, Teresa Anguera M. How game location affects soccer performance: T-pattern analysis of attack actions in home and away matches. Front Psychol. 2017;8(1):1-11.

416. Gonzalez-Rodenas J, Lopez-Bondia I, Calabuig F, Antonio Perez-Turpin J, Aranda R. The effects of playing tactics on creating scoring opportunities in random matches from US Major League Soccer. Int J Perf Anal Sport. 2015;15(3):851-72.
417. Gonzalez-Rodenas J, Lopez-Bondia I, Calabuig F, Antonio Perez-Turpin J, Aranda R. Association between playing tactics and creating scoring opportunities in counterattacks from United States Major League Soccer games. Int J Perf Anal Sport. 2016;16(2):737-52.
418. Gonzalez-Rodenas J, Lopez-Bondia I, Calabuig F, James N, Aranda R. Association between playing tactics and creating scoring opportunities in elite football. A case study in Spanish football national team. J Hum Sport Exerc. 2015;10(1):65-80.
419. Gonzalez-Rodenas J, Lopez-Bondia I, Calabuig F, Pérez-Turpin JA, Aranda R. Creation of goal scoring opportunities by means of different types of offensive actions in US Major League soccer. Hum Mov. 2017;18(5):106-16.
420. Hwang J-W, Kim JH, Hong S-J. An analysis of comparison on performances in soccer attacking-third. Korean J Sport Sci. 2013;24(4):653-61.
421. Janković A, Leontijević B, JelušIć V, Pašić M, Mićović B. Influence of tactics efficiency on results in Serbian Soccer Super League in season 2009/2010. J Phys Educ Sport. 2011;11(1):32-41.
422. Lago J, Lago C, Rey E, Casáis L, Domínguez E. The offensive success in elite football. Influence of the tactical models used and the situational variables. Mot Eur J Hum Mov. 2012;28(1):145-70.
423. Leontijević B, Janković A, Tomić L. Tactics of attack of football teams in the Champions League knockout phase in seasons 2015/16 and 2016/17. Phys Cult. 2017;71(2):137-44.
424. Lopez Bondia I, Gonzalez-Rodenas J, Calabuig Moreno F, Antonio Perez-Turpin J, Aranda Malaves R. Creating goal scoring opportunities in elite soccer. Tactical differences between Real Madrid CF and FC Barcelona. Retos: Nuevas Tendencias Educ Fis Deporte Recreac. 2017;32(2):233-7.
425. López-Botella M, Palao JM. Relationship between laterality of foot strike and shot zone on penalty efficacy in specialist penalty takers. Int J Perf Anal Sport. 2007;7(3):26-36.
426. Lourenco dos Santos FJ, Sarmento H, Mendes B, Mauricio N, Furtado B, Sousa PM, et al. Complementary analysis of goal in football through notational analysis, sequential analysis and T-patterns detection. Rev Bras Futsal Futeb. 2017;9(34):238-49.
427. Machado JC, Barreira D, Garganta J. The influence of match status on attacking patterns of play in elite soccer teams. Rev Bras Cineantropometria Desempenho Hum. 2014;16(5):545-54.
428. Mahony LE, Wheeler KW, Lyons K. Analysis of factors determining invasion into attacking areas and the creation of goal-scoring opportunities in the Asian Cup Football Competition. Asian J Exerc Sports Sci. 2012;9(1):53-66.
429. Maneiro R, Ardá T, Rial A, Losada JL, Casal CA, López-García S. Descriptive and comparative analysis of the corners. UEFA Euro 2012. Rev Andal Med Deporte. 2017;10(3):95-9.
430. Mara JK, Wheeler KW, Lyons K. Attacking strategies that lead to goal scoring opportunities in high level women's football. Int J Sports Sci Coach. 2012;7(3):565-78.
431. Miljkovic Z, Jerovic S, Simenc Z. Evaluation of a model of monitoring individual and team performance during attack in a competitive soccer game. Kinesiology. 2002;34(1):73-85.
432. Pulling C. Long corner kicks in the English Premier League: Deliveries into the goal area and critical area. Kinesiology. 2015;47(2):193-201.
433. Pulling C, Newton J. Defending corner kicks in the English Premier League: Near-post guard systems. Int J Perf Anal Sport. 2017;17(3):283-92.
434. Pulling C, Robins M, Rixon T. Defending corner kicks: Analysis from the English Premier League. Int J Perf Anal Sport. 2013;13(1):135-48.

435. Sainz De Baranda P, Lopez-Riquelme D. Analysis of corner kicks in relation to match status in the 2006 World Cup. Eur J Sport Sci. 2012;12(2):121-9.
436. Sarmento H, Figueiredo A, Lago-Penas C, Milanovic Z, Barbosa A, Tadeu P, et al. Influence of tactical and situational variables on offensive sequences during elite football matches. J Strength Cond Res. 2018;32(8):2331-9.
437. Seaton M, Campos J. Distribution competence of a football clubs goalkeepers. Int J Perf Anal Sport. 2011;11(2):314-24.
438. Taylor JB, Mellalieu SD, James N, Barter P. Situation variable effects and tactical performance in professional association football. Int J Perf Anal Sport. 2010;10(3):255-69.
439. Tenga A, Holme I, Ronglan LT, Bahr R. Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. J Sport Sci. 2010;28(3):245-55.
440. Tenga A, Holme I, Ronglan LT, Bahr R. Effect of playing tactics on goal scoring in Norwegian professional soccer. J Sport Sci. 2010;28(3):237-44.
441. Tenga A, Ronglan LT, Bahr R. Measuring the effectiveness of offensive match-play in professional soccer. Eur J Sport Sci. 2010;10(4):269-77.
442. Tenga A, Sigmundstad E. Characteristics of goal-scoring possessions in open play: Comparing the top, in-between and bottom teams from professional soccer league. Int J Perf Anal Sport. 2011;11(3):545-52.
443. Tokul E, Mülazımoğlu O. Analyzing the process from the initiation of attack to goal scoring touch in the EURO 2016. Univers J Educ Res. 2018;6(12):2738-42.
444. Wright C, Atkins S, Polman R, Jones B, Sargeson L. Factors associated with goals and goal scoring opportunities in professional soccer. Int J Perf Anal Sport. 2011;11(3):438-49.
445. Yiannakos A, Armatas V. Evaluation of the goal scoring patterns in European Championship in Portugal 2004. Int J Perf Anal Sport. 2006;6(1):1-13.
446. Alcock A. Analysis of direct free kicks in the women's football World Cup 2007. Eur J Sport Sci. 2010;10(4):279-84.
447. Almeida CH, Volossovitch A, Duarte R. Penalty kick outcomes in UEFA club competitions (2010-2015): The roles of situational, individual and performance factors. Int J Perf Anal Sport. 2016;16(2):508-22.
448. Casal CA, Losada JL, Maneiro R, Arda T. Influence of match status on corner kicks tactics in elite soccer. Rev Int Med Cienc Act Fis Deporte. 2017;17(68):715-28.
449. Fariña RA, Fábrica G, Tambusso PS, Alonso R. Taking the goalkeeper's side in association football penalty kicks. Int J Perf Anal Sport. 2013;13(1):96-109.
450. Hoch T, Tan X, Leser R, Baca A, Moser BA. A knowledge discovery framework for the assessment of tactical behaviour in soccer based on spatiotemporal data. Math Comput Model Dyn Syst. 2017;23(4):384-98.
451. Szczepański Ł. Measuring the effectiveness of strategies and quantifying players' performance in football. Int J Perf Anal Sport. 2008;8(2):55-66.
452. Zhang P, Beernaerts J, Zhang L, Van de Weghe N. Visual exploration of match performance based on football movement data using the Continuous Triangular Model. Appl Geogr. 2016;76:1-13.
453. Clemente FM, Couceiro MS, Martins FML, Mendes R, Figueiredo AJ. Measuring collective behaviour in football teams: Inspecting the impact of each half of the match on ball possession. Int J Perf Anal Sport. 2013;13(3):678-89.
454. Grehaigne J-F, Godbout P, Zerai Z. How the "rapport de forces" evolves in a soccer match: the dynamics of collective decisions in a complex system. Rev Psicol Deporte. 2011;20(2):747-65.
455. Gréhaigne JF, Bouthier D, David B. Dynamic-system analysis of opponent relationships in collective actions in soccer. J Sport Sci. 1997;15(2):137-49.

456. Ramos J, Lopes RJ, Marques P, Araújo D. Hypernetworks reveal compound variables that capture cooperative and competitive interactions in a soccer match. Front Psychol. 2017;8(1):1-12.
457. Vilar L, Araujo D, Davids K, Bar-Yam Y. Science of winning soccer: Emergent pattern-forming dynamics in association football. J Syst Sci Complex. 2013;26(1):73-84.
458. Bartlett R, Button C, Robins M, Dutt-Mazumder A, Kennedy G. Analysing team coordination patterns from player movement trajectories in soccer: Methodological considerations. Int J Perf Anal Sport. 2012;12(2):398-424.
459. Castellano J, Álvarez D. Defensive use of the interaction space in soccer. Rev Int Cienc Deporte. 2013;9(32):126-36.
460. Castellano J, Alvarez-Pastor D, Blanco-Villasenor A. Analysing the space for interaction in soccer. Rev Psicol Deporte. 2013;22(2):437-46.
461. Castellano J, Casamichana D. What are the differences between first and second divisions of Spanish football teams? Int J Perf Anal Sport. 2015;15(1):135-46.
462. Clemente F, Santos-Couceiro M, Lourenco-Martins F, Sousa R, Figueiredo A. Intelligent systems for analyzing soccer games: The weighted centroid. Ing Investig. 2014;34(3):70-5.
463. Clemente FM, Couceiro MS, Martins FML, Mendes RS, Figueiredo AJ. Using collective metrics to inspect spatio-temporal relationships between football players. S Afr J Res Sport Phys Educ Recreat. 2014;36(2):47-59.
464. Clemente FM, Martins FML, Couceiro MS, Mendes RS, Figueiredo AJ. Evaluating the offensive definition zone in football: A case study. S Afr J Res Sport Phys Educ Recreat. 2014;36(3):25-37.
465. Clemente FM, Martins FML, Couceiro MS, Mendes RS, Figueiredo AJ. Inspecting teammates' coverage during attacking plays in a football game: A case study. Int J Perf Anal Sport. 2014;14(2):384-400.
466. Duarte R, Araújo D, Correia V, Davids K, Marques P, Richardson MJ. Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. Hum Mov Sci. 2013;32(4):555-66.
467. Duarte R, Araújo D, Folgado H, Esteves P, Marques P, Davids K. Capturing complex, non-linear team behaviours during competitive football performance. J Syst Sci Complex. 2013;26(1):62-72.
468. Folgado H, Duarte R, Marques P, Sampaio J. The effects of congested fixtures period on tactical and physical performance in elite football. J Sport Sci. 2015;33(12):1238-47.
469. Memmert D, Raabe D, Schwab S, Rein R. A tactical comparison of the 4-2-3-1 and 3-5-2 formation in soccer: A theory-oriented, experimental approach based on positional data in an 11 vs. 11 game set-up. PloS One. 2019;14(1):1-12.
470. Tenga A, Zubillaga A, Caro O, Fradua L. Explorative study on patterns of game structure in male and female matches from elite Spanish soccer. Int J Perf Anal Sport. 2015;15(1):411-23.
471. Zubillaga A, Gabbett TJ, Fradua L, Ruiz-Ruiz C, Caro O, Ervilla R. Influence of ball position on playing space in Spanish elite women's football match-play. Int J Sports Sci Coach. 2013;8(4):713-22.
472. Bialkowski A, Lucey P, Carr P, Matthews I, Sridharan S, Fookes C. Discovering team structures in soccer from spatiotemporal data. IEEE Trans Knowl Data Eng. 2016;28(10):2596-605.
473. Castellano J, Alvarez D, Figueira B, Coutinho D, Sampaio J. Identifying the effects from the quality of opposition in a football team positioning strategy. Int J Perf Anal Sport. 2013;13(3):822-32.
474. Perl J, Memmert D. A pilot study on offensive success in soccer based on space and ball control - Key performance indicators and key to understand game dynamics. Int J Comput Sci Sport(De Gruyter Open). 2017;16(1):65-75.

475. Siegle M, Lames M. Modeling soccer by means of relative phase. J Syst Sci Complex. 2013;26(1):14-20.
476. Clemente FM, Couceiro MS, Lourenco Martins FM, Mendes RS. Using network metrics in soccer: A macro-analysis. J Hum Kinet. 2015;45(1):123-34.
477. Clemente FM, Couceiro MS, Martins FML, Mendes RS. Using network metrics to investigate football team players' connections: A pilot study. Mot J Phys Educ. 2014;20(3):262-71.
478. Clemente FM, Lourenco Martins FM, Kalamaras D, Wong DP, Mendes RS. General network analysis of national soccer teams in FIFA World Cup 2014. Int J Perf Anal Sport. 2015;15(1):80-96.
479. Clemente FM, Lourenco Martins FM, Mendes RS. Analysis of scored and conceded goals by a football team throughout a season: A network analysis. Kinesiology. 2016;48(1):103-14.
480. Clemente FM, Martins FML, Couceiro MS, Mendes RS, Figueiredo AJ. A network approach to characterize the teammates' interactions on football: A single match analysis. Cuad Psicol Deporte. 2014;14(3):141-8.
481. Clemente FM, Martins FML, Kalamaras D, Oliveira J, Oliveira P, Mendes RS. The social network analysis of Switzerland football team on FIFA World Cup 2014. J Phys Educ Sport. 2015;15(1):136-41.
482. Couceiro M, Dias G, Silva JP, Araujo D. Adaptive collective behavior of the players of the Portuguese national team in the 2016 European Football Championship. Rev Bras Futsal Futeb. 2018;10(40):523-30.
483. Gama J, Couceiro M, Dias G, Vaz V. Small-world networks in professional football: Conceptual model and data. Mot Eur J Hum Mov. 2015;35(1):85-113.
484. Gama J, Passos P, Davids K, Relvas H, Ribeiro J, Vaz V, et al. Network analysis and intra-team activity in attacking phases of professional football. Int J Perf Anal Sport. 2014;14(3):692-708.
485. Lee H, Kim J-E, Park J-C. A study on the pass analysis of football game using social networking analysis. J Digit Converg. 2017;15(7):479-87.
486. McLean S, Salmon PM, Gorman AD, Naughton M, Solomon C. Do inter-continental playing styles exist? Using social network analysis to compare goals from the 2016 EURO and COPA football tournaments knock-out stages. Theor Issues Ergon Sci. 2017;18(4):370-83.
487. McLean S, Salmon PM, Gorman AD, Stevens NJ, Solomon C. A social network analysis of the goal scoring passing networks of the 2016 European Football Championships. Hum Mov Sci. 2018;57(1):400-8.
488. Clemente FM. Performance outcomes and their associations with network measures during FIFA World Cup 2018. Int J Perf Anal Sport. 2018;18(6):1010-23.
489. Clemente FM, Jose F, Oliveira N, Lourenco Martins FM, Mendes RS, Figueiredo AJ, et al. Network structure and centralization tendencies in professional football teams from Spanish La Liga and English Premier Leagues. J Hum Sport Exerc. 2016;11(3):376-89.
490. Clemente FM, Lourenco Martins FM, Wong DP, Kalamaras D, Mendes RS. Midfielder as the prominent participant in the building attack: A network analysis of national teams in FIFA World Cup 2014. Int J Perf Anal Sport. 2015;15(2):704-22.
491. Clemente FM, Martins FML. Network structure of UEFA Champions League teams: Association with classical notational variables and variance between different levels of success. Int J Comput Sci Sport(De Gruyter Open). 2017;16(1):39-50.
492. Clemente FM, Martins FML. Study of sequences of passes between professional soccer player in home matches during a season: Applicability of social network analysis measures. Rev Iberoam Psicol Ejerc Deporte. 2017;12(2):195-202.
493. Clemente FM, Martins FML. Who are the prominent players in the UEFA champions league? An approach based on network analysis. Walailak J Sci Technol. 2017;14(8):627-36.

494. Clemente FM, Silva F, Lourenco Martins FM, Kalamaras D, Mendes RS. Performance analysis tool for network analysis on team sports: A case study of FIFA Soccer World Cup 2014. Proc Inst Mech Eng P J Sport Eng Technol. 2016;230(3):158-70.
495. Ignacio Ortega J, Evangelio C, Clemente FM, Lourenco Martins FM, Gonzalez-Villora S. Analysis of physiological, technical, and tactical analysis during a friendly football match of elite U19. Sports. 2016;4(2):1-14.
496. Malta P, Travassos B. Characterization of the defense-attack transition of a soccer team. Motricidade. 2014;10(1):27-37.
497. Mendes B, Clemente FM, Mauricio N. Variance in prominence levels and in patterns of passing sequences in elite and youth soccer players: A network approach. J Hum Kinet. 2018;61(1):141-53.
498. Peixoto D, Praca GM, Bredt S, Clemente FM. Comparison of network processes between successful and unsuccessful offensive sequences in elite soccer. Hum Mov. 2017;18(4):48-54.
499. Pina TJ, Paulo A, Araujo D. Network characteristics of successful performance in association football. A study on the UEFA Champions League. Front Psychol. 2017;8(1):1-7.
500. Belli RJ, Figueiredo Dias GN, Travassos Ventura Gama JM, Simoes Vaz VP, da Silva CD. Network and collective behavior in professional football teams. Rev Bras Futsal Futeb. 2017;9(32):84-94.
501. Fernandez-Navarro J, Fradua L, Zubillaga A, Ford PR, McRobert AP. Attacking and defensive styles of play in soccer: Analysis of Spanish and English elite teams. J Sport Sci. 2016;34(24):2195-204.
502. Lago-Penas C, Gomez-Ruano M, Yang G. Styles of play in professional soccer: An approach of the Chinese Soccer Super League. Int J Perf Anal Sport. 2017;17(6):1073-84.
503. Gómez M-Á, Mitrotasios M, Armatas V, Lago-Peñas C. Analysis of playing styles according to team quality and match location in Greek professional soccer. Int J Perf Anal Sport. 2018;18(6):986-97.
504. Fernandez-Navarro J, Fradua L, Zubillaga A, McRobert AP. Influence of contextual variables on styles of play in soccer. Int J Perf Anal Sport. 2018;18(3):423-36.
505. Gollan S, Ferrar K, Norton K. Characterising game styles in the English Premier League using the "moments of play" framework. Int J Perf Anal Sport. 2018;18(6):998-1009.
506. Gomez M-A, DelaSerna A, Lupo C, Sampaio J. Effects of situational variables and starting quarter score in the outcome of elite women's water polo game quarters. Int J Perf Anal Sport. 2014;14(1):73-83.
507. Argudo FM, Arias JL, Ruiz E. Effect to take the first ball possession on score in water polo. Rev Int Med Cienc Act Fis Deporte. 2011;11(44):738-48.
508. Choi H. The investigation of team performance analysis based on the 2002, 2006 football World Cup data. Korean J Meas Eval Phys Educ Sport Sci. 2009;11(2):41-51.
509. Escalante Y, Saavedra JM, Tella V, Mansilla M, Garcia-Hermoso A, Dominguez AM. Differences and discriminatory power of water polo game-related statistics in men in international championships and their relationship with the phase of the competition. J Strength Cond Res. 2013;27(4):893-901.
510. García-Marín P, Manuel F, Iturriaga A, Alonso Roque JI. The game action of the power play in water polo by periods. Retos: Nuevas Perspectivas Educ Fis Deporte Recreac. 2015;27(1):14-8.
511. Ozkol MZ, Turunc S, Dopsaj M. Water polo shots notational analysis according to player positions. Int J Perf Anal Sport. 2013;13(3):734-49.
512. del Carmen Iglesias Pérez M, Ordóñez EG, González CT. Game-related statistics in the Spanish Water Polo League: Differences between seasons. Retos: Nuevas Perspectivas Educ Fis Deporte Recreac. 2018;33(1):228-32.

513. Garcia Ordonez E, Tourino Gonzalez C, Iglesias Perez MdC. Offensive performance indicators in a regular season of water-polo. Int J Perf Anal Sport. 2015;15(3):1114-23.
514. Garcia-Ordonez E, Tourino-Gonzalez C, del Carmen Iglesias-Perez M. Effects of situational variables on offensive performance indicators in elite water polo. Int J Perf Anal Sport. 2017;17(1-2):164-76.
515. Iglesias Perez MdC, Garcia Ordonez E, Tourino Gonzalez C. Keys to success in high level water polo teams. Int J Perf Anal Sport. 2016;16(3):995-1006.
516. Iglesias Perez MdC, Garcia Ordonez E, Tourino Gonzalez C. Game-related statistics in the Spanish Water Polo League: Differences between seasons. Retos: Nuevas Tendencias Educ Fis Deporte Recreac. 2018;33(1):228-32.
517. Iturriaga FMA, Cervantes LG, Lara ER. Factors associated with shooting efficacy in water polo. Retos. 2016;29(1):105-8.
518. Saavedra JM, Escalante Y, Madera J, Mansilla M, García-Hermoso A. Comparison of game-related statistics in men's international championships between winning and losing teams according to margin of victory. Coll Antropol. 2014;38(3):901-7.
519. Sahrom S, Chen S, Tan F, Kong PW, Lee M. Short-term influence of rule changes on match characteristics in water polo. J Phys Educ Sport. 2018;18(Suppl 1):503-11.
520. Garcia Ordonez E, Iglesias Perez MdC, Tourino Gonzalez C. Performance assessment in water polo using compositional data analysis. J Hum Kinet. 2016;54(1):143-51.
521. Ricardo I, Alfredo DT, Gaetano R. Pilot work on evaluation of women water polo tactics pattern. Ovidius Uni Annals Ser Phys Educ Sport/Sci Mov Health. 2012;12(2):159-65.
522. Passos P, Davids K, Araújo D, Paz N, Minguéns J, Mendes J. Networks as a novel tool for studying team ball sports as complex social systems. J Sci Med Sport. 2011;14(2):170-6.
523. Franjković A, Matković B, Milanović D. Situational efficiency parameters of successful and unsuccessful ice hockey teams at IIHF World Championship division I B. Baltic J Sport Health Sci. 2017(3):34-40.
524. Szulc AM. The report and analysis of the first U21 European Deaf Football Championship men, Wroclaw, Poland 2016. Hum Mov. 2017;18(2):44-8.
525. Gomez MA, Molik B, Morgulec-Adamowicz N, Szyman RJ. Performance analysis of elite women's wheelchair basketball players according to team-strength, playing-time and players' classification. Int J Perf Anal Sport. 2015;15(1):268-83.
526. Gómez MÁ, Pérez J, Molik B, Szyman RJ, Sampaio J. Performance analysis of elite men's and women's wheelchair basketball teams. J Sport Sci. 2014;32(11):1066-75.
527. Koo DH, Panday SB, Xu DY, Lee CY, Kim HY. Logistic regression of wins and losses in Asia League ice hockey in the 2014-2015 Season. Int J Perf Anal Sport. 2016;16(3):871-80.
528. Pérez-Tejero J, Pinilla J, Vanlandewijck Y. Performance profile at the Basketball World Championship (Ankara 2013) for people with intellectual disabilities: Implications for eligibility system. Rev Iberoam Psicol Ejerc Deporte. 2015;10(2):187-92.
529. Macdonald B. Adjusted plus-minus for NHL players using ridge regression with goals, shots, fenwick, and corsi. J Quant Anal Sports. 2012;8(3):1-24.
530. Hyrinen M, Juntunen J, Blomqvist M, Vermark S, Molik B, Kosmol A, et al. Match analysis of elite ice sledge hockey in Paralympics 2010. J Quant Anal Sports. 2011;7(3):1-16.
531. Lupo C, Capranica L, Ammendolia A, Rizzuto F, Tessitore A. Performance analysis in youth waterbasket - A physiological, time motion, and notational analysis of a new aquatic team sport. Int J Perf Anal Sport. 2012;12(1):1-13.
532. Vinson D, Peters DM. Position-specific performance indicators that discriminate between successful and unsuccessful teams in elite women's indoor field hockey: Implications for coaching. J Sport Sci. 2016;34(4):311-20.

533. Yanci J. Analysis of goals scored by players with cerebral palsy in official football 7-a-side matches. Kinesiology. 2015;47(2):202-7.
534. Clear C, Hughes M, Martin D. Attacking profiles in elite hurling. Int J Perf Anal Sport. 2017;17(3):319-33.
535. Hirofumi M, Aya M, Makoto K, Kenichi K, Koya S, Masafumi Y. The comparison of attacking aspects between the international level and domestic level in amputee soccer tournament. Int J Sport Health Sci. 2018;16(1):1-9.
536. Navarro A, Morillo JP, Reigal RE, Hernández-Mendo A. Polar coordinate analysis in the study of positional attacks in beach handball. Int J Perf Anal Sport. 2018;18(1):151-67.
537. Bock JR. Empirical prediction of turnovers in NFL football. Sports. 2016;5(1):1-11.

2.7 Link to Experimental Studies

The findings from the systematic review emphasise that practical performance analysis techniques should capture the dynamic, complexity of team invasion sports, but present this information in simplified formats to provide practical insights on how teams create and defend goal scoring opportunities. Practical techniques revolved around identifying game styles, team structures, player networks and movement patterns. The concepts behind these ideas were utilised when developing methods for the experimental studies based on extracting the greatest amount of strategical information using the limited resources available.

Declaration of Co-Authorship for Thesis Chapter 3

DECLARATION BY CANDIDATE

In the case of Chapter 3 the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Study design, analysis and interpretation, manuscript preparation	80

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Dr Jocelyn Mara	Design, analysis, editing	No
Prof David Pyne	Design, analysis, editing	No
Dr Marijke Welvaert	Design, analysis, editing	No

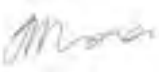
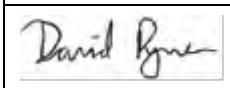
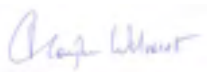
19/01/22

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: Research Institute for Sport and Exercise, University of Canberra

Signatures	Date
	28/01/22
	28/01/22
	28/01/22

Chapter 3 - Field hockey from the performance analyst's perspective: A systematic review

Lord F, Pyne DB, Welvaert M, Mara JK. (2022) Field hockey from the performance analyst's perspective: A systematic review. *International Journal of Sports Science & Coaching* 17: 220-232.

Abstract

Field hockey is an evolving sport however it is unclear whether performance analysis techniques are reflective of current best practice. The objective of this review was to identify performance analysis methods used in field hockey, assess their practicality, and provide recommendations on their implementation in the field. A systematic search of the databases SPORTDiscus, Web of Science, Scopus, MEDLINE and PubMed was performed. Key words addressed performance analysis methods and field hockey, with all other disciplines of sport science excluded. A total of 8 articles were identified from the systematic review. Three studies explored patterns of play in relation to goal scoring opportunities, two articles examined penalty corner strategies and three compared specific actions in hockey. The limited performance analysis research in field hockey has focused on game actions in patterns of play. However, greater insights may be gained by analysing hockey using a holistic approach that incorporates spatio-temporal variables and player-opposition interactions. There is an opportunity to employ novel performance analysis techniques in hockey which provide more practical and effective approaches for analysing strategies and tactics.

Key words: game actions, penalty corners, patterns of play

3.1 Introduction

Field hockey is a team invasion sport played on a 91.4 m long and 55 m wide artificial turf field, consists of four 15 min quarters and a team may have no more than 11 players on the field at one time. The aim of the game is to outscore the opposition team by moving the ball into the opposition's circle and shooting at goal. According to the Federation of International Hockey (FIH), a goal is scored when the ball crosses completely over the goal line and under the cross bar having been played from within the circle by an attacking player (FIH Rules of Hockey 2019). Thus, the circle is the key attacking area in hockey. Strategies are therefore developed to create effective attacking circle entries and prevent the opposition from entering this area. In the last two decades, FIH have introduced rule changes to maximise the pace and flow of the game and increase the number of goal scoring opportunities. These changes include removing the offside rule[1], introducing the self-pass rule allowing a player to dribble the ball from a stoppage[2], and changing the time periods of the game from 2 x 35 min halves to 4 x 15 min quarters. As the game has evolved rapidly, so too have the game strategies that have been implemented by coaches, in order to utilise the skills, and adapt to the speed of the modern game.

Performance analysis is the discipline of observing and analysing tactical and strategical behaviour in sport. The purpose of performance analysis is to provide objective information about a sporting performance that can be used to identify team and player strengths, and areas that can be improved.[3] Performance analysts have traditionally captured outcome-focused variables such as the number of goal shots, penalty corners or turnovers.[4] Although these variables may reflect the outcome of a match, they do not provide insight into individual team strategies and therefore the practical impact of outcome-orientated analysis is limited. However, the field of performance analysis has evolved rapidly given advancements in technology such as computerised video analysis software and tracking devices.[5, 6] These developments have resulted in a marked increase in data generation and availability, making it possible to employ process-orientated analysis that combines player actions, spatio-temporal measures and player-opposition interactions.[5] The evolution in data capture technology and variables collected underpins the ongoing change in the contemporary perspectives of team invasion sports.

Team invasion sports are now perceived by researchers as a dynamic, complex system with the teams as interacting parts.[7-10] A dynamic complex system is defined as an open system with multiple interacting parts, where each interaction is short ranged and influenced by the

history of the system, and consequently the system has no equilibrium.[11] Capturing the holistic nature of sport by recording game actions in relation to opposition interactions and spatio-temporal measures accounts for this dynamic complexity.[7-10] Current best practice analysis techniques in research include analysing team structure through collective team behaviours,[12, 13] intra-team dynamics using social network analysis,[14-16] unpredictability through entropy measures[17] and identifying game styles which reflect consistent team strategies.[18-19] These techniques may be more effective than outcome-focused performance analysis techniques as they provide practical insight *how* a team played or *why* they achieved certain outcomes by analysing the processes involved. These techniques allow an analyst to provide information to a coach to inform strategy development by identifying what they want to achieve, and how and why they can achieve it. For example, using game styles analysis in hockey, an analyst can identify for a coach that the opposition consistently uses long over heads from deep in defence to clear the ball to space for their quick strikers to run onto and counter attack. The coach can then use this information to develop a strategy to thwart this attack by instructing their team to apply high pressure to the ball carrier to limit their ability to throw these long passes and have the deepest defenders positioned in the areas where the ball is likely to be passed to. However, in practice these techniques may be difficult to implement given limited access to required technology, a lack of sufficient data analysis skills, or the time required to analyse spatio-temporal data collected. These challenges may limit performance analyst's use of video and notational analysis in international hockey to provide immediate feedback to coaches, which is critical during major tournaments when there is a short turnaround between games. There is a need to close the gap between techniques in research and practice, and enhance analysis and implementation of tactics and strategies using the time, resources and skills available to performance analysts in the field.

No systematic review has been conducted to explore the use and application of performance analysis techniques in field hockey. With an evolving field of performance analysis, there is a need to determine whether methods of performance analysis in hockey reflect current best practice techniques. The aim of this review was to identify performance analysis techniques used to analyse hockey tactics and strategy, evaluate the practicality of these methods and provide recommendations on practical techniques to use in the field.

3.2 Methods

3.2.1 Search Strategy: Design, Inclusion and Exclusion Criteria

A systematic review was conducted on performance analysis techniques in hockey according to PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses). The search was completed on 2 August 2020. Electronic databases used were SPORTDiscus, Web of Science, Scopus, MEDLINE and PubMed. No time frame was specified in the search criteria; earliest publications relating to key search terms until August 2020 were extracted from the databases to be screened for relevance. Key search terms were selected based on the objectives of the study and joined using the Boolean search term OR; "performance analysis", "notational analysis", "match analysis", "game analysis", "tactical analysis", "patterns of play", "strategy", "game styles", "performance indicators", "dynamic systems", "systems analysis", "sports analytics", "performance analytics" and "team behaviour". The context was limited by searching for "field hockey" using the AND function. Another set of key terms that reflected themes to be excluded were joined using NOT; "injury", "injury prevention", "recovery", "physical demands", "match demands", "loading", "match load", "technique", "biomechanics", "running", "conditioning", "fitness", "physiology" and "psychology".

To increase accuracy, two independent reviewers (FL and JM) assessed the publications separately using the process outlined in Section 3.2.2, and the inclusion and exclusion criteria described below, to determine their eligibility in the review. The inclusion criteria for the articles were: (1) analysis of data related to the evaluation of technical indicators, tactical movement patterns or strategies was presented; (2) participants were amateur or professional adult male or female athletes; (3) the sport studied was field hockey; and (4) from a peer-reviewed scientific journal. Articles were excluded if: (1) the participants were children (15 years or under); (2) match outcome, goals/points statistics or skill involvements were reported without reference to a tactical or strategic method; (3) the study contained themes relating to medicine, health, injuries, injury prevention, biomechanical, physical, nutrition, psychological or teaching; (4) the study only described a theoretical model or analysed the reliability or validity of an analysis tool without applying it to a real world data set; (5) were a conference abstract, narrative review or systematic review; and/or (6) the articles were not in English. If an article included both features of the inclusion and exclusion criteria, results are only reported for the relevant features. Where there was a disagreement on the inclusion of articles, then the final decision was left to the first author (FL) given greater experience on the subject matter.

3.2.2 Quality of Studies and Data Extraction

The initial database search returned 67 articles. Duplicate articles were removed leaving 53 article titles and abstracts to be screened for relevance. A further 32 articles were excluded following this process. The remaining 21 full articles were examined, and another 13 articles omitted due to not meeting the inclusion criteria. The final sample consisted of 8 articles for systematic review. The screening process is illustrated in Figure 3.1.

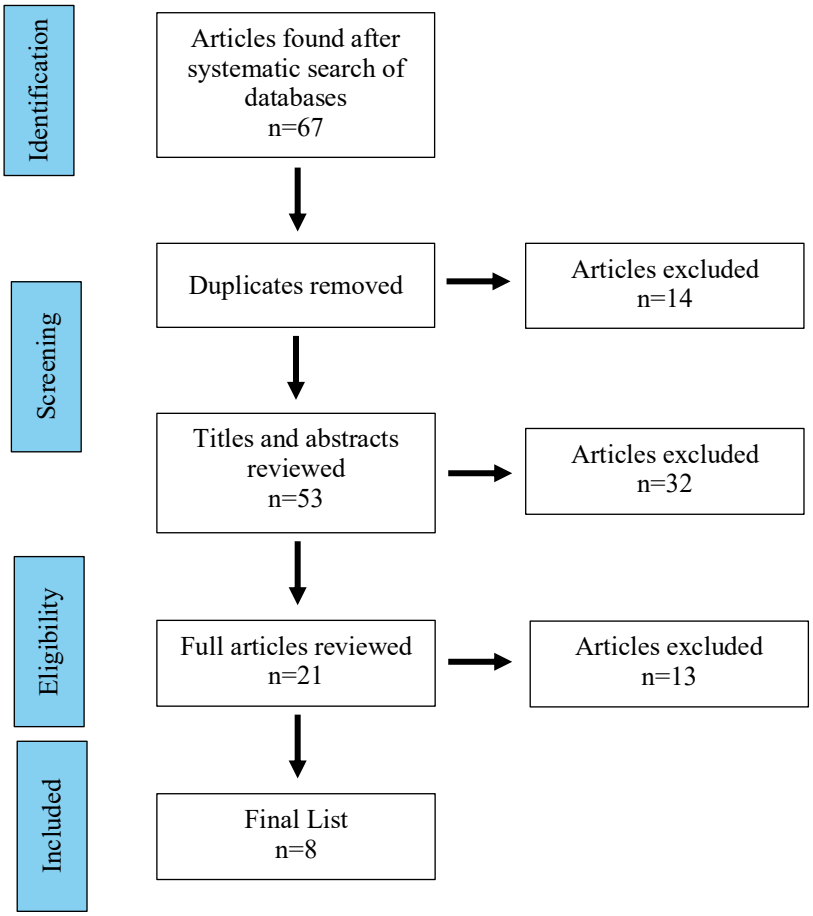


Figure 3.1 Screening process for selection of field hockey performance analysis articles

The quality of research of the included articles was separately assessed by two independent reviewers (FL and JM) using a modified version of the Strengthening of Reporting of Observational Studies in Epidemiology (STROBE) Statement.[20] The checklist used, detailed in Table 3.1, was adapted to reflect the methodological strategies in sports performance analysis observational studies. The checklist assessed the validity and reliability of methods,

the statistical analysis procedures used and usefulness of the results and discussion. This level of detail is important to clearly identify inherent limitations when interpreting and comparing studies. Articles could yield a maximum score of 23 points, with one point allocated to each item from the checklist.

Table 3.1 Quality assessment checklist items for the modified version of STROBE (Strengthening of Reporting of Observational Studies in Epidemiology) checklist

Item	Item No	Recommendation
Title	1A	Indicate the study's design with a commonly used term in the title or the abstract
Abstract	1B	Provide in the abstract an informative and balanced summary of what was done and what was found
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
Objectives	3	State specific objectives
Study design	4	Present key elements of study design early in the paper e.g. Live or post game data capture, external database
Setting	5	Describe the setting, locations, and relevant dates of data collection e.g. tournament, year, number of games
Participants	6	Describe the cohort of participants e.g. gender, playing level, quality of team
Variables	7	Cleary define all raw and outcome variables collected and analysed
Data sources/management	8	Gives details of tools used to capture and analyse data
Bias	9	Describe any efforts to address potential sources of bias
Reliability	10	Conduct intra or inter reliability assessments for data capture tools
Study size	11	Explain how the study size was arrived at
Quantitative variables	12	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	13A	Describe all statistical methods, including those used to control for confounding variables
	13B	Describe any methods used to examine subgroups and interactions
	13C	Explain how missing data were addressed
Descriptive data	14	Report mean and variability measures of all outcome variables
Main results	15	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g. 95% confidence interval). Make clear which confounders were adjusted for and why they were included
Inferential analysis	16	Significant or practical differences reported
Key results	17	Summarise key results with reference to study objectives
Limitations	18	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	19	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	20	Discuss the generalisability (external validity) of the study results
Total	/23	

3.3 Results

A description of the studies included in the systematic review is provided in Table 3.2. Included studies were published between 1 April 2003 and 30 April 2015. Two articles describe effective penalty corner routines,[21, 22] three articles investigate patterns of play [2, 23, 24] and short and long corners,[25] short and long passing sequences[26] and number of substitutions[27] were compared in one article each. Articles were separated into outcome and process-orientated articles to reflect the approach taken in analysing the data. Outcome-orientated articles reported *what* happened; in contrast process-orientated methods describe the *how, where* and *why* in relation to the outcome. Four articles were identified as outcome-orientated[21, 25-27] and four articles identified as process-orientated.[2, 22-24]

3.3.1 Penalty Corner Routines

Research exploring penalty corner routines indicated that a goal was 11% more likely to be scored from a penalty corner when the ball left the ground as opposed to a goal shot that did not leave the ground.[21] Substantial differences in successful penalty corner routines were identified between males and females. Males were 23-63% more likely to score from a direct shot from the outer edges of the circle using a drag flick.[22] In contrast, females were 18-36% more likely to score by passing the ball and creating a deflection close to goal.[22]

3.3.2 Patterns of Play

The most likely strategy leading to goal scoring opportunities was repossessing the ball in the attacking half, moving the ball down the edges of the field and entering the circle by dribbling through the sides of the circle, and then shooting from a hit at the top of the circle or a deflection close to goal.[23, 24] The introduction of the self-pass rule also decreased the time to engage in free hits by 3.5 secs, reach the attacking 25 from the defensive areas by 2.5-6.0 secs, and increased the percentage of circle entry types by dribbling by 24% and number of goal shots from circle entries by 8%.[2]

3.3.3 Comparative Studies

In the comparison of short and long corners, 34% more short corners were converted into goals than long corners.[25] Short passing sequences were also 9x more effective at creating goal scoring opportunities than long passing sequences.[26] Moreover, when a high frequency of substitutions was utilised as opposed to no substitutions of strikers, the strikers completed 39% more technical actions.[27]

Table 3.2 Performance analysis articles in field hockey

Article	Objective	Sample	Methods	Results
Amjad et al., (2013)	Comparison of long and short corners and their relation to success	*Gender:* Not specified *Cohort:* National teams *Tournament:* World Cup 2010 *Matches:* 6 *Corners:* 32 long and 30 short	*Approach:* Outcome-orientated *Capture:* Dartfish Classroom Plus *Statistical Analysis:* Chi Square	• 40% of short corners and 6% of long corners resulted in a goal • 73% of goal shots from centre of circle for short corners and 53% of goal shots from left side of circle from long corners • 63% of goal shots were lifted from short corners and 89% of goal shots were hit along the ground from long corners • 57% of short corners and 96% of long corners involved 3 or more players • 55% of unsuccessful short corner outcomes were saved, 16% were due to a foul, 31% of unsuccessful long corners were due to loss of possession and 25% due to a foul
Ariff et al., (2015)	Comparison of short and long passing sequences and their relation to success	*Gender*: Male *Cohort:* National teams *Tournament:* World Hockey League Semi Final 2013 *Matches:* 24	*Approach:* Outcome-orientated *Capture:* SportsCode Elite *Reliability tests:* Intra and inter-observer *Statistical Analysis:* Wilcoxon Rank Test	• 4102 short and 512 long passing sequences before a field goal or penalty corner was awarded • Push most likely way to pass short, slap most likely way to pass the ball long • 28x more likely to have circle entry, 9x more likely to score field goal, 44x more likely to win penalty corner for short than long passing sequences
Laird and Sutherland (2003)	Describe the most effective penalty corner routines	*Gender:* Not specified *Cohort:* National teams *Tournament:* World Cup 1998 *Matches:* 84 *Penalty Corners:* 250	*Approach:* Outcome-orientated *Capture:* Hand notation and video recording	• 3.0 penalty corners per game, 1.4 penalty corner goals per game • A goal was 11% more likely when the ball was flicked or undercut compared to hit along the ground

Table 3.2 continued

Article	Objective	Sample	Methods	Results
				• The most common reason for not scoring from a penalty corner was when the ball was saved or team lost possession
Lythe and Kilding (2013)	The effect of substitutions on technical output of strikers	*Gender:* Not specified *Cohort:* National players *Experimental conditions:* (1) 3 strikers, no subs (2) 4 strikers, moderate frequency subs (3) 5 strikers, high frequency subs *Matches:* 5	*Approach:* Outcome-orientated *Capture:* SportsCode Elite *Reliability tests:* Intra and inter-observer *Statistical Analysis:* Paired T tests	• 39% more technical contributions were observed from condition 1 to 3 • A 36% decrease in technical contributions between 1st and 2nd half for no substitution condition
Pineiro et al., (2007)	Comparison of penalty corner strategies between men and women	*Gender:* Male and female *Cohort:* National teams *Tournaments*: • Men; Champions Trophy 2003, 9th European Nations Cup 2003, Olympic Qualifiers 2004 • Women; 6th European Nations Cup, Champions Trophy 2004 *Matches:* 38 men, 21 women *Penalty Corners:* 81 men, 47 women	*Approach: Process*-orientated *Capture:* Video observation *Statistical Analysis:* Chi square	• Men more likely to score a penalty corner goal from a drag flick (63%), using 3 players (38%), 1 pass (37%), from the right area far from goal (23%) • Women more likely to score a penalty corner goal from a hit (23%), push (11%) or deflection (22%) using 4 players (36%), 3 passes (31%), from the left (18%) or right (20%) areas close to goal • No difference observed between shot direction at goal
Stockl and Morgan (2013)	Observe spatial characteristics of ball movements in relation to goal scoring opportunities	*Gender:* Female *Cohort:* National teams *Tournament:* Olympics 2008 *Matches:* 15	*Approach: Process*-orientated *Capture:* Video recording, Pattern Plotter	• Most frequent areas of possession for all teams was the right side of the field • Circle entry more likely to occur if ball was moved down the sides of the field than through the centre

Table 3.2 continued

Article	Objective	Sample	Methods	Results
			Analysis: ISOPAR method	• Goal shot most likely to occur if ball was possessed near top or at top centre of circle • Attacking patterns can be observed for each team individually, illustrating differences in goal scoring capacity of teams
Sunderland et al., (2006)	Investigate patterns of play resulting in goals scored	*Gender:* Female *Cohort:* National teams *Tournaments:* Olympic Qualifiers 2000, Olympics 2000, Commonwealth Games 2002 *Matches:* 70 *Goals:* 130	*Approach: Process*-orientated *Capture:* Video recording and hand notation *Reliability tests:* Intra and inter-observer	• Pattern of play most likely to lead to a goal: o Repossessing the ball in attacking half by free hit or interception o Dribbled into the right side of the circle o Goal shot was a hit from outer edge of circle or deflection close to goal directed to bottom corners of goal o No difference observed between goal shots taken from left or right of circle
Tromp and Holmes (2011)	The effect of rule changes on patterns of play	*Gender:* Female *Cohort:* National teams *Tournaments:* Champions Trophy 2008 and 2009 *Matches:* 28 (14 per year)	*Approach: Process*-orientated *Capture:* SportsCode Elite *Reliability tests:* Intra-observer *Statistical Analysis:* Mann-Whitney Test	• Decrease in time to take a free hit from 2008 (8.0±0.9s) to 2009 (4.6±0.3s) • The time taken to enter the attacking 25-yard area decreased when ball was repossessed in defensive left (-6.0s), defensive 25-yard left (-2.5s), attacking mid (-2.0s) but increased from attacking 25 right (+1.5s) • Marked differences between methods of entering the circle, most notably increase in dribbling from 33 to 57% • 12% increase in number of penalty corners, 8% increase in goal shots and 4% decrease in turnovers from circle entries • No differences observed between type of goal shot and goal shot directions

3.3.4 Quality Assessment

Table 3.3 illustrates the results of the quality of research assessment using the modified STROBE statement. Results ranged from 2 - 18 points with the majority of articles scoring poorly in the methods section by failing to clearly define variables, and failing to report the validity and reliability of the procedures employed.

Table 3.3 Quality assessment of field hockey performance analysis studies using a modification of the STROBE (Strengthening of Reporting of Observational Studies in Epidemiology) checklist

Item	Item No.	Amjad et al., (2013)	Ariff et al., (2015)	Laird and Sutherland (2003)	Lythe and Kilding (2013)	Pineiro et al., (2007)	Stockl and Morgan (2013)	Sunderland et al., (2006)	Tromp and Holmes (2011)
Title	1A	N	N	N	N	N	N	N	N
Abstract	1B	N	Y	Y	Y	N	N	Y	Y
Background/rationale	2	N	N	N	Y	Y	Y	Y	Y
Objectives	3	Y	Y	N	Y	Y	Y	Y	Y
Study design	4	N	N	N	Y	N	Y	Y	Y
Setting	5	Y	Y	Y	Y	Y	Y	Y	Y
Participants	6	N	N	N	N	Y	Y	Y	Y
Variables	7	N	N	N	N	Y	Y	Y	Y
Data sources/management	8	Y	Y	N	Y	N	Y	Y	Y
Bias	9	N	N	N	N	N	N	N	N
Reliability	10	N	Y	N	Y	N	Y	Y	Y
Study size	11	N	N	N	N	N	N	N	N
Quantitative variables	12	N	N	N	Y	Y	Y	Y	Y
Statistical methods	13A	N	N	N	N	Y	Y	N	Y
	13B	N	N	N	N	N	Y	N	N
	13C	N	N	N	N	N	N	N	N
Descriptive data	14	Y	Y	N	Y	Y	Y	Y	Y
Main results	15	N	N	N	N	Y	Y	N	N
Inferential analysis	16	Y	Y	N	Y	Y	Y	N	Y
Key results	17	Y	Y	N	Y	Y	Y	Y	Y
Limitations	18	N	N	N	Y	N	Y	Y	N
Interpretation	19	Y	Y	N	Y	Y	Y	Y	Y
Generalisability	20	N	Y	N	Y	N	Y	Y	Y
Total	/23	7	10	2	14	12	18	15	16

3.4 Discussion

Although performance analysis is a growing field the research investigating hockey is limited with only 8 articles identified from the systematic review. The three main areas of research identified were effective penalty corners routines, patterns of play leading to goal scoring opportunities and comparative studies of specific game events. The studies identified all focused on game actions, with some providing greater situational context (e.g. locations on the field) than others. Although these studies provide insights into effective strategies for scoring, the techniques employed were limited to notational analysis and reporting mean values or total game actions. No studies have yet provided analysis using emerging best practice techniques such as entropy to identify unpredictability, or neural networks to develop game style profiles that encompass the holistic nature of sport. There is an opportunity to employ current best practice performance analysis techniques (used in other team invasion sports[5]) in hockey, to provide more practical and effective analyses of team strategy and tactics.

Specific game actions have been studied in hockey providing insight into different parts of the game. Identifying effective attacking actions is always a priority for coaches. In this regard, penalty corners were 34% more likely to be converted into a goal than long corners,[25] which highlights the importance of the set piece. Shorter passing sequences were also 9x more effective than longer passing sequences at creating goal scoring opportunities indicating that a more direct style of play is more effective in hockey.[26] There was a 39% increase in the number of technical actions completed by strikers when a greater number of substitutions occurred per game,[27] reflecting the influence of situational factors on tactical performance. These comparative studies highlight more effective tactics for specific areas of the game. However, the variables analysed in these studies are predominantly outcome-orientated, in that they identify the effect of that game action on success but do not describe the processes involved to reach a successful outcome. For example, in regard to passing sequences,[26] this type of analysis does not indicate whether the location on the field, the defensive structure or the number of players involved affect the outcome of short or long passing sequences. This shortcoming limits the practicality of these analysis methods as they don't provide insight that can be used to develop strategies based on a dynamic, complex system.

Penalty corners are a key strategic play in hockey, contributing to ~55% of all goals scored.[28] Thus, penalty corners are a key area of the game and employing effective strategies can improve the likelihood of competitive success. Laird and Sutherland[21] showed that a goal was

11% more likely to be scored from a penalty corner when the ball was undercut or flicked at the goal in comparison to when the ball did not leave the ground. Unfortunately, the location and the direction of the goal shots were not recorded which limits the context and practicality of these results. The gender distribution of players was also not specified, nor was a detailed statistical analysis conducted. Pineiro et al.[22] then investigated effective penalty corner routines for both men and women. Substantial differences were observed between the most likely ways to score for men and women highlighting the need for individualised strategies based on the physical capabilities of the players. A goal was 63% more likely to be scored by male players than female from a drag flick, 23% more likely from the right outer edges of the circle, and 38% more likely when there were 3 players involved.[22] In contrast, female players were 22% more likely than male to score from a deflection, 37% more likely from the areas close to goal, 31% more likely when 3 passes were made, and 36% more likely when there were 4 players involved.[22] This study identified the most likely ways to score by detailing the processes involved to create a goal scoring opportunity. However, a rule change introduced in 2006 limited the bow of the stick to 25mm (FIH Rules of Hockey 2006) which would have an impact on the ability to drag flick. Although drag flicking was identified as an effective method of scoring from penalty corners, both the Laird and Sutherland[21] and Pineiro et al.[22] studies were completed prior to this rule change when a larger bowed stick allowed high speeds to be achieved when drag flicking. Therefore, this may not currently be the best method.

Future studies should analyse the impact of the stick bow depth rule change and identify what are the current most effective penalty corner routines based on the skills and equipment of modern-day players. Nonetheless, this is a method that can be used in practice as analysis can be completed post-match if the game is captured on video allowing individual team routines to be identified. However, further insight can be gained by assessing the degree of predictability of a team's attacking penalty corner routines. Unpredictability is linked to success as it creates uncertainty in the defence.[29] Teams with greater variations on this effective routine could be more successful which is an area that needs exploring in future research. The inclusion of spatial variables and player dynamics should provide greater insight for a coach to use to develop effective penalty corner strategies based on the strengths of their team, making it a more practical performance analysis technique to use in the field.

Successful patterns of play are the most commonly investigated area of performance analysis research in hockey. The first study published in this area was by Sunderland et al.[24] who

analysed patterns of play leading to 130 goals from 70 matches of international women's hockey from 2000 to 2002. The variables analysed included where and how the ball was repossessed, how the ball entered the circle, goal shot locations and goal shot types. The pattern of play most likely to lead to a successful goal scoring opportunity was repossessing the ball in the attacking half via a free hit or interception, dribbling the ball through the right side of the circle and hitting the ball from the outer edge of the circle or a deflection close to goal.[24] Similar findings in an analysis of international female teams were demonstrated by Stockl and Morgan[23] who tracked the movement of the ball and analysed the patterns using the ISOPAR method. ISOPAR is a method of visualising movement patterns and associated probability of an outcome through contour maps. Moving the ball along the edges of the field and entering through the side of the circle before moving the ball to the top of the circle was the most effective path to goal.[23] However, it is unclear whether practically significant differences are evident between these movement patterns or the degree they are related to success. Analysing patterns of play is a practical approach to performance analysis as it illuminates the processes involved in developing effective attacks. Incorporating the speed of attack and defensive pressure, as well as match context would provide greater insight into different match situations.

Stockl and Morgan[23] also illustrated individualised attacking strategies for each team, highlighting the different teams' goal scoring capabilities. The top 3 teams had greater possession in the attacking half, whereas the bottom 3 ranked teams had concentrated possession in their defensive half, illustrating their difficulties in creating goal scoring opportunities. The majority of teams demonstrate a right-side bias as this is the stronger side given all players use a right-handed stick whereas the left side, on the reverse is generally weaker. However, the top ranked team, Netherlands, had greater possession along the left-hand side of the field illustrating a different strategy to goal - this outcome supports the notion there is not one way to win a game. The individual analysis of teams provides a practical approach to analysing hockey as it highlights the key differences between teams' strategies.

Rule changes can have a substantial effect on patterns of play and influence the strategies and tactics implemented by teams. The most recent rule changes in hockey were investigated by Tromp and Holmes[2] by comparing patterns of play in international hockey from the year before and after the rule change was made. Modifications were made to the taking of free hits in 2009. The 'self-pass' was introduced which enabled the player taking the free hit to play

the ball to themselves, or dribble from a free hit, as opposed to having to pass the ball to a team mate before being allowed to be involved in the play again. This rule change also affected the taking of free hits inside the attacking 25, as the ball cannot be played straight into the circle from a free hit - it must travel 5 metres first. After the rule modification, there was a decrease in time in taking free hits, increasing the speed and free-flowing nature of the game which was the intention of the rule.[2] There was also a decrease in time to reach the attacking 25 from the defensive areas of the field. However, given the inability to play the ball straight into the circle from a free hit from the attacking 25, it forced teams to take alternate routes passing the ball outside the attacking 25. Consequently, there was an increase in time taken to enter the attacking 25 again. A 24% increase in dribbling to enter the circle was also identified and 8% more goal shots were recorded illustrating implementation of more effective attacking strategies.[2] This study illustrates the effect rule changes can have on game variables underpinning the need to quantify how teams adapt to these changes in both practical and research settings.

It is evident that there is limited research investigating performance analysis in hockey and the methods used to analyse the data often have not reflected current best practice techniques. In general, the methods reflect traditional approaches by focusing on notational analysis of game action variables, and often with a small sample size, lack clarity in defining objectives, populations or methods or lack inferential testing to understand if there is a practical difference between variables or patterns of play. Greater emphasis must be placed on employing valid and reliable methods so that the study outcomes may be transferred into a practical setting. To provide a greater understanding of strategies in hockey investigators should utilise current best practice techniques (Figure 3.2) that capture and analyse performance in a holistic manner by accounting for space, time and opposition interaction. These techniques include collective team behaviours,[12, 13] social network analysis,[14-16] entropy[17] and game styles[18, 19] as they provide the greatest transfer of information from a theoretical to a practical setting.

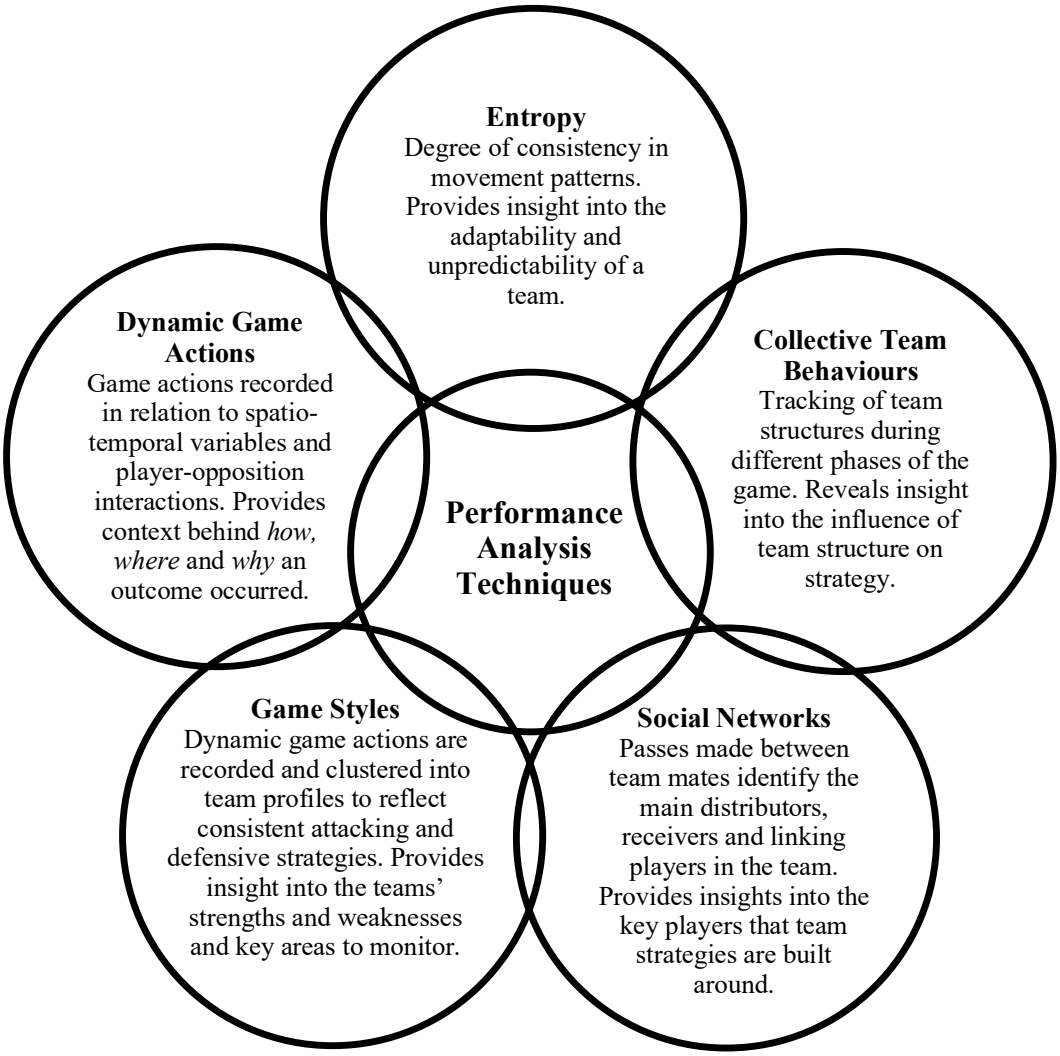


Figure 3.2 Summary of performance analysis techniques capturing performance as a dynamic, complex system

Analytic methods have been investigated in other team invasion-based sports and have generated useful results, so implementation of these methods in hockey has the potential for similar valuable outcomes. For example, in relation to collective team behaviours in Australian Football, teams increase their length, width and surface area during offence to disrupt the opposition structure, but in defence they contract to protect the area closest to goal.[12] In soccer, social network analysis has shown that lateral defenders and midfielders were the key players that initiated attacks that lead to goal scoring opportunities.[15] In basketball, a greater value of entropy or unpredictability in attack was evident for higher deficit wins than smaller deficit wins or large deficit losses.[17] Game styles were built around five moments of play in both soccer and Australian Football; established attack, transition attack, transition defence, established defence and set pieces which were used to highlight

areas of strengths and weaknesses of individual teams reflecting key strategies they utilise to win.[18, 19] These are practical methods for developing strategies, based on the strengths and weaknesses of individuals and team structure, rather than just focusing on the outcomes of game actions. These techniques can be applied to analysing strategy in hockey. For example, identifying a team's defensive structure from a free hit in the defensive 25 compared to attacking 25, understanding a team's ball movement patterns to create goal scoring opportunities when winning or losing, identifying the players with high passing ability versus those with exceptional running and dribbling skills, or identifying whether a team is more likely to score from established attacks, counter attacks or set pieces to understand the need to limit these opportunities.

Data analysis methods can also be adopted from other scientific disciplines and applied to sports data to provide additional insights. The backward dropping algorithm is a genomic selection method that reduces a large number of variables into a smaller subset that best distinguishes a trait.[30] This method was applied to the analysis of a small sample of games in hockey as it has the advantage of not needing a large number of observations (games) to build the model.[30] This can be an issue in hockey when there is limited international tournaments occurring and consequently limited information available per team. The aim was to identify relationships between spatio-temporal metrics and positive and negative outcomes of play. Over 3600 metrics were evaluated, however only passing execution and proximity to goal were able to distinguish between plays ending in a circle entry and those resulting in a turnover.[30] Studying and applying alternative data analysis methods, such as the backward dropping algorithm, will provide new perspectives to analysing strategies and tactics in sport.

To link research to practice we must understand why current performance analysis methods are used and the limitations of more contemporary techniques in practice. For example, Stockl and Morgan[23] used a program called Pattern Plotter to manually track ball movements in a retrospective analysis. Although results were insightful, the time-consuming nature of the task could deter analysts from conducting this type of analysis. To alternatively track the ball live during a game would be more efficient, but would also be less reliable decreasing the value of the results. Newer technology is now available such as semi-automated tracking systems, however this technology is expensive and may not be a viable option for some teams. Semi-automated systems can also be used to track player positions to provide the data on collective team behaviours. Global (GPS) or local positioning systems (LPS) can also be used but without access to the opposition team's data this information does not provide an

entire picture of the game. Entropy, social network analysis and game styles are all developed from notational analysis data but require further analyses. For example, game styles can be produced by clustering similar variables into profiles using neural networks. This higher level analysis necessitates that performance analysts upskill their data science skills to extract and interpret different insights into the data they already have collected. Alternatively, software could be developed to provide these analysis tools for analysts so they may just input their data they have collected, and then results are produced in simple, accessible and concise formats for coaches, players and support staff. Greater automation of processing should mean performance analysts can focus their time on understanding, discussing, and implementing the insights in practice. Research into performance analysis in hockey needs to continue to explore these contemporary data collection and analysis methods to increase the depth of knowledge of effective tactics and strategies in hockey, and provide valid and reliable techniques that can be applied in the field.

Hockey performance analysis in research and practice has been limited by the resources available. We consider that methods of analysis can be improved with the resources currently available to analysts working directly with hockey coaches and players. Using basic equipment such as a camera and notational analysis system, analysts should focus on capturing data in relation to time, location, opposition interaction and match context. For example, recording the type and location of a turnover and pressure from the opposition rather than just the total number of turnovers in a game. This level of analysis will facilitate a very extensive pipeline of practical insights to be obtained from the resources and time committed in the field, in combination with the ongoing development of the data analysis skills of individual analysts.

In conclusion, there is limited research into performance analysis in hockey, and methods employed typically do not reflect current and emerging best practice approaches. Studies have examined the patterns of play leading to goal scoring opportunities, penalty corner routines and comparative studies of specific game events. Team invasion sport is currently viewed as a dynamic, complex system and performance analysis methods should reflect this view by analysing hockey from a holistic approach that combines player actions, spatio-temporal measures and player-opposition interactions.

3.5 References

1. Asembo, J, Mwisukha, A, Njororai, W. The effect of the offside rule abolition on selected offensive actions, fouls and injuries in field hockey. *Afr J Phys Health Edu Recreat Dance* 1998; 4: 9-22.
2. Tromp, M, Holmes, L. The effect of free-hit rule changes on match variables and patterns of play in international standard women's field hockey. *Int J Perf Anal Sport* 2011; 11: 376-391.
3. Wright, C, Atkins, S, Jones, B, et al. The role of performance analysts within the coaching process: Performance Analysts Survey 'The role of performance analysts in elite football club settings'. *Int J Perf Anal Sport* 2013; 13: 240-261.
4. Hughes, MD, Bartlett, RM. The use of performance indicators in performance analysis. *J Sports Sci* 2002; 20: 739-754.
5. Lord, F, Pyne, DB, Welvaert M, et al. Methods of performance analysis in team invasion sports: a systematic review. *J Sports Sci* 2020; 38: 2338-2349.
6. Barris, S, Button, C. A review of vision-based motion analysis in sport. *Sports Med* 2008; 38: 1025-1043.
7. Ribeiro, J, Davids, K, Araújo, D, et al. The role of hypernetworks as a multilevel methodology for modelling and understanding dynamics of team sports performance. *Sports Med* 2019; 49: 1337-1344.
8. Ribeiro, J, Silva, P, Duarte, R, et al. Team sports performance analysed through the lens of social network theory: implications for research and practice. *Sports Med* 2017; 47: 1689-1696.
9. Soltanzadeh, S, Mooney, M. Systems thinking and team performance analysis. *Int Sport Coach J* 2016; 3: 184-191.
10. Travassos, B, Davids, K, Araujo, D, et al. Performance analysis in team sports: advances from an ecological dynamics approach. *Int J Perf Anal Sport* 2013; 13: 83-95.
11. Salmon, PM, McLean, S. Complexity in the beautiful game: implications for football research and practice. *Sci Med Football* 2020; 4: 162-167.
12. Alexander, JP, Spencer, B, Mara, JK, et al. Collective team behaviour of Australian Rules football during phases of match play. *J Sports Sci* 2019; 37: 237-243.
13. Alexander, JP, Spencer, B, Sweeting, AJ, et al. The influence of match phase and field position on collective team behaviour in Australian Rules football. *J Sports Sci* 2019; 37: 1699-1707.
14. Clemente, FM, Lourenco Martins, FM, Kalamaras, D, et al. General network analysis of national soccer teams in FIFA World Cup 2014. *Int J Perf Anal Sport* 2015; 15: 80-96.

15. Clemente, FM, Lourenco Martins, FM, Mendes, RS. Analysis of scored and conceded goals by a football team throughout a season: a network analysis. *Kinesiology* 2016; 48: 103-114.
16. Clemente, FM, Lourenco Martins, FM, Wong, DP, et al. Midfielder as the prominent participant in the building attack: a network analysis of national teams in FIFA World Cup 2014. *Int J Perf Anal Sport* 2015; 15: 704-722.
17. Hobbs, W, Morgan, S, Gorman, AD, et al. Playing unpredictably: measuring the entropy of ball trajectories in international women's basketball. *Int J Perf Anal Sport* 2018; 18: 115-126.
18. Gollan, S, Ferrar, K, Norton, K. Characterising game styles in the English Premier League using the "moments of play" framework. *Int J Perf Anal Sport* 2018; 18: 998-1009.
19. Greenham, G, Hewitt, A, Norton, K. A pilot study to measure game style within Australian football. *Int J Perf Anal Sport* 2017; 17: 576-585.
20. Vandenbroucke, JP, Von Elm, E, Altman, DG, et al.; for the STROBE Initiative. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. *PLoS Med* 2007; 4: 1628-1654.
21. Laird, P, Sutherland, P. Penalty corners in field hockey: a guide to success. *Int J Perf Anal Sport* 2003; 3: 19-26.
22. Piñeiro, RM, Molinuevo, JS, Román IR. Differences between international men's and women's teams in the strategic action of the penalty corner in field hockey. *Int J Perf Anal Sport* 2007; 7: 67-83.
23. Stöckl, M, Morgan, S. Visualization and analysis of spatial characteristics of attacks in field hockey. *Int J Perf Anal Sport* 2013; 13: 160-178.
24. Sunderland, C, Bussell, C, Atkinson, G, et al. Patterns of play and goals scored in international standard women's field-hockey. *Int J Perf Anal Sport* 2006; 6: 13-29.
25. Amjad, I, Hussain, I, Asadullah, M. Comparison between long corners and short corners in field hockey. *Rawal Med J*. 2013; 38: 428-431.
26. Ariff, M, Norasrudin, S, Rahmat, A, et al. Passing sequences towards field goals and penalty corners in men's field hockey. *J Hum Sport Exerc* 2014; 10: S638-S647.
27. Lythe, J, Kilding, AE. The effect of substitution frequency on the physical and technical outputs of strikers during field hockey match play. *Int J Perf Anal Sport* 2013; 13: 848-859.
28. Piñeiro, R, Sampedro, J, Refoyo, I. Análisis de la estrategia en el hockey hierba de alto rendimiento. *I Congreso Internacional de Ciencias del Deporte*, 2006. Pontevedra.

29. Neuman, Y, Israeli, N, Vilenchik, D, et al. The adaptive behavior of a soccer team: an entropy-based analysis. *Entropy* 2018; 20: 758-769.
30. McInerney, C. Determining spatio-temporal metrics that distinguish play outcomes in field hockey. Sheffield: Sheffield Hallam University, 2017.

Declaration of Co-Authorship for Thesis Chapter 4

DECLARATION BY CANDIDATE

In the case of Chapter 4 the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Study design, analysis and interpretation, manuscript preparation	80

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Dr Jocelyn Mara	Design, analysis, editing	No
Prof David Pyne	Design, analysis, editing	No
Dr Marijke Welvaert	Design, analysis, editing	No

19/01/22

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: Research Institute for Sport and Exercise, University of Canberra

Signatures	Date
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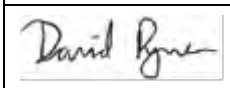
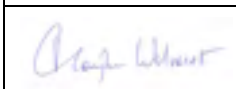
	28/01/22
	28/01/22

Chapter 4 - Identifying and analysing game styles and factors influencing a team's strategy in field hockey

Lord F, Pyne DB, Welvaert M, Mara JK. (2022) Identifying and analysing game styles and factors influencing a team's strategy in field hockey. *Journal of Sports Sciences* 40: 908-919.

Abstract

Characterising a team's game style is a performance analysis approach that captures game events, and groups them into profiles using clustering techniques to identify the consistent (and winning) strategies a team implements. The aim of this study was to identify the game styles of international hockey teams. Video footage from the 2019 Pro League tournament (n = 74 female, n = 57 male matches) were analysed retrospectively using a notational analysis system in SportsCode™. Variables were arranged into six game style categories (established attack game actions, counter attack game actions, established attack success, counter attack success, set piece occurrence, tempo) and two game style types identified per category using a k-means clustering algorithm. Decision trees were used to identify the influence of extrinsic and intrinsic match factors on the probability of a team playing a particular game style. Opposition and other reference team game style categories were shown to be more important in predicting a game style category than contextual factors. Examination of team profiles highlights how different strategies are successful for different teams such as a high defensive pressure and game possession attack, or absorbing pressure and counter attacking. This performance analysis process provides practical insights into the holistic performance of international hockey teams.

Key words: performance analysis, strategy, team analysis, sports analytics

4.1 Introduction

Team invasion sports can be characterised as a dynamic, complex system where players interact with their team mates and the opposition in a constantly changing environment (Ribeiro et al., 2019; Ribeiro et al., 2017; Soltanzadeh & Mooney, 2016). This scenario reflects the complexities of understanding and being successful in team invasion sports. Although both teams strive to outscore the opponent to win the game, there is more than one way to achieve this outcome. Coaches develop attacking and defensive strategies that they believe will give them the greatest chance of success by considering the strengths and weaknesses of both their team and the opposition (Grehaigne et al., 1999). To ensure effective strategies are developed, a coach or analyst must view the game from a holistic perspective to reflect the dynamic, complex system (Lord et al., 2020). This process is known as analysing a game style.

Game styles have been defined as the consistent attacking and defensive strategies implemented by a team (Hewitt et al., 2016). Quantifying game styles is a relatively new method of performance analysis where variables are grouped or clustered into profiles using methods such as factor analyses or neural networks (Croft et al., 2015; Gomez et al., 2018). Styles may be based on match situations such as in soccer where game styles were based on five moments of play: set pieces, established attack, established defence, transition attack, and transition defence (Gollan et al., 2018). These moments of play reflect the control a team has over possession during a match. Set pieces involve one team having control over the possession, established phases reflect moments when teams are structured and balanced, and progression of ball movement is slower, and transition moments reflect a change in possession when teams are unstructured and unbalanced allowing the opportunity for fast ball movement (Hewitt et al., 2016). Three game styles were identified from these moments: teams being moderately strong in established defence, teams being stronger in transition moments, and teams being stronger in established attack and set pieces (Gollan et al., 2018). Alternatively, a game style can be based on dynamic game actions such as in rugby union where a ball-carrying high contact game style, and a low possession kicking game style were identified as winning strategies for different teams (Croft et al., 2015). This method of analysis exposes the complex nature of sport, and the effects that the opposition and interactions of performance variables have on success (Croft et al., 2015). Traditional statistical methods often mask or fail to identify these variables.

The advantage of dynamic analysis of game styles is that it provides a holistic approach to viewing performance. This allows key areas to be identified that need monitoring for individual teams within a match and development of training exercises to target opposition teams' strengths and weaknesses. For example, in netball previous games against an upcoming opponent were assessed and both successful and unsuccessful game styles were identified (Croft et al., 2017). Allowing the wing attack to receive the centre pass, but not the goal attack, and stopping the centre receiving the following pass, were identified as key tactics associated with preventing the opposition from scoring (Croft et al., 2017). This key tactic was then measured live during the game: the team were able to win by 1 goal which is reflected in the game style where tactics were only successfully implemented 50% of the time (Croft et al., 2017). This example also highlights that knowing what to do, executing targeted strategies during a game, and adaptability to the changing situation, are important determinants of the game outcome.

Match context (such as match status, quality of the opposition and match location) can also affect the likelihood of a particular game style being implemented (Fernandez-Navarro et al., 2018; Gollan et al., 2020; Gomez et al., 2018; Gonzalez-Rodenas et al., 2021). For example, in soccer, results of a logistic regression analysis revealed teams were more likely to implement a defensive style when playing at home (Gollan et al., 2020). However, regardless of match location, teams would implement an attacking style against bottom-ranked sides, and a defensive or transition style against top-ranked sides (Gollan et al., 2020). Similarly, soccer teams that were losing increased their use of playing styles associated with possession, such as build-up and sustained threat plays, and decreased their use of direct play (Fernandez-Navarro et al., 2018). Comparatively, when winning, teams increased their use of direct play and counter attacks and decreased their use of maintenance, build-up and sustained threat plays. These outcomes highlight the need to identify game styles under different match conditions so a coach can plan for different match situations.

Investigations into performance analysis methods in field hockey are limited in number, and are reflective of traditional approaches focusing on game outcomes without considering the influence of spatio-temporal or contextual variables (Lord et al., 2022). Game styles have not yet been identified in field hockey so there is an opportunity to provide a novel method of analysing hockey that provides useful practical insights into a team's strategy. Therefore, the primary aim of this study was to identify game styles in international hockey teams based on the clustering of similar dynamic game actions. A secondary aim was to identify the effect of

extrinsic contextual variables and intrinsic game factors on the probability of game styles being played under different match conditions.

4.2 Methods

Video footage of 131 matches (n = 57 male, n = 74 female) from the 2019 International Hockey Federation (FIH) Pro League were accessed and analysed. Hockey Australia provided access to the data base of video footage captured from each match during the tournament. The majority of games included video footage captured from each respective team's analyst from behind the goals which provides a greater view of the field. This output was synced with video footage from TV coverage of the game filmed from a side on angle that is zoomed in on the player with the ball. The tournament is an invitational competition played in a home and away season by 8 and 9 teams for men and women respectively, ranked within the top 12 FIH teams in international hockey. Teams included Argentina, Australia, Belgium, China (women only), Great Britain, Germany, Netherlands, New Zealand, Spain (men only) and United States of America (women only). Ethics approval was granted by the University of Canberra Human Research Ethics Committee.

Computerised performance analysis software, SportsCode™ (Version 11, Hudl, https://www.hudl.com) was used to analyse the video footage and capture notational game data. The code window used for the notational analysis is illustrated in Figure 4.1. All game actions and events were recorded in relation to the location on the field, speed of attack, defensive pressure, and their effectiveness. The definitions of all variables and their labels are presented in Supplementary Resources 4.1 - 4.3. Extrinsic contextual variables were also recorded for each game and included the match location for each team (home or away), match status for each team at the time of the event (winning, losing or drawing) and quality of the reference team and opposition determined by the team ranking at the conclusion of the tournament (top = 1^{st} - 4^{th}, bottom = 5^{th} - 8^{th}/9^{th}). The code window and definitions were produced in consultation with national team performance analysts and coaches to ensure applicability to the real world. A pilot study was completed on a randomly selected game from the database to test the code window and ensure all necessary variables were recorded.

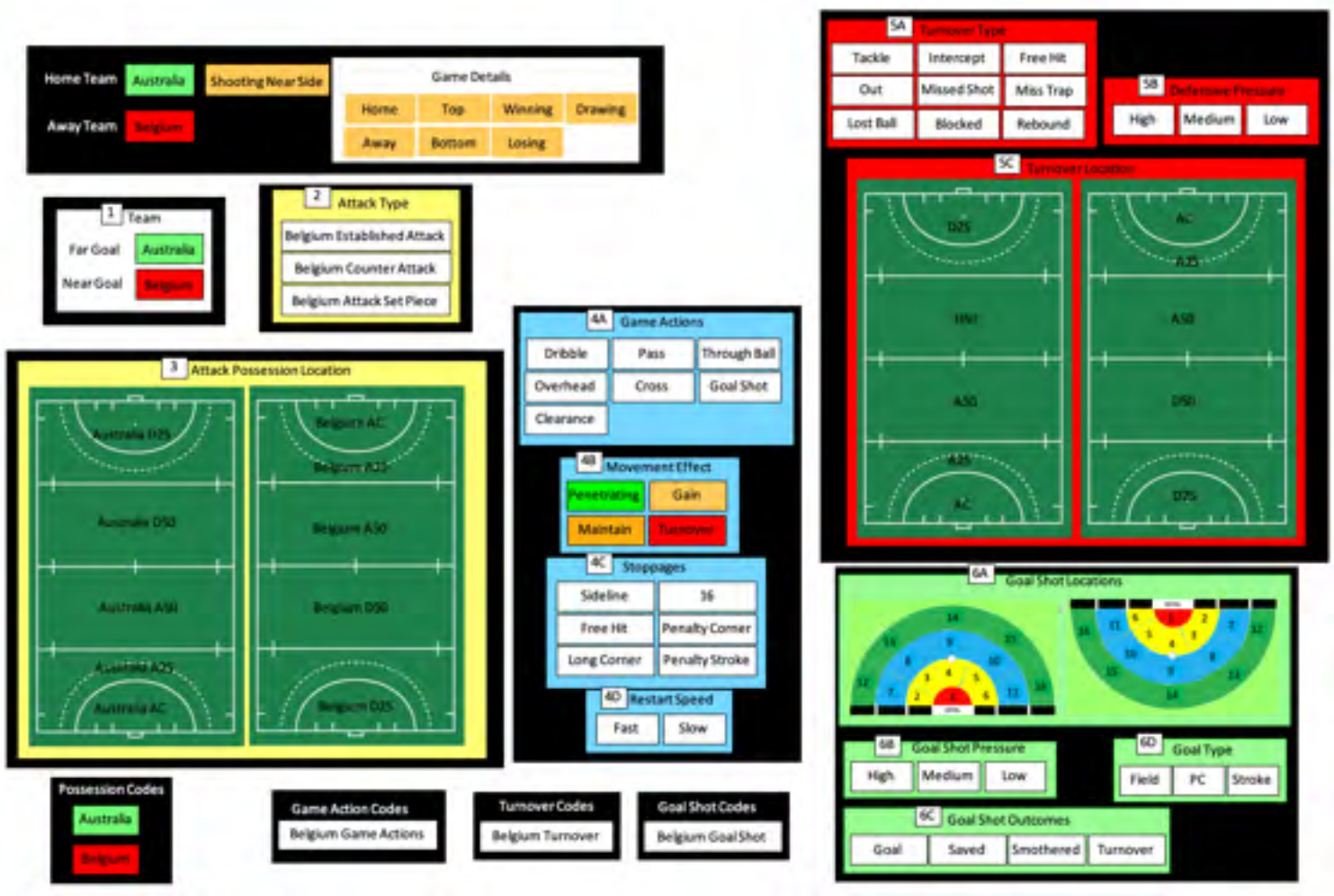


Figure 4.1 Notational analysis system used to capture game variables in SportsCode to create game styles. The number boxes illustrate the steps to follow to code a sequence of play by selecting the team in possession, attack type, field location, and then options for in game events available in boxes 4-6. The code window provides an example of a game between Australia (home team) and Belgium (away team).

Additionally, to ensure the methods were reliable, intra- and inter-coder reliability tests were conducted by two coders independently on a random selection of games from the database, with at least 100 observations per variable analysed. One of the coders was the lead author (FL) and an experienced hockey analyst, and both coders were high-level hockey players. The Kappa coefficients for intra and inter-coder reliability tests are displayed in Table 4.1. All Kappa values were between 0.86 - 1, indicating "very good" agreement between observers (Altman, 1991) and that the code window is a reliable tool for capturing field hockey data.

Table 4.1 Results of the inter- and intra-coder reliability analysis. Kappa values and interpretations; <0.20 = poor, 0.21 - 0.40 = fair, 0.41 - 0.60 = moderate, 0.61 - 0.80 = good, 0.81 - 1.00 = very good.

	Kappa Coefficients	
Variable	**Inter-coder**	**Intra-coder**
Game Actions	0.96	1
Movement Effect	0.87	0.97
Location	0.96	1
Attack Type	0.92	0.97
Stoppages	0.98	1
Restart Speed	0.94	0.94
Goal Shot Location	0.92	0.91
Goal Shot Pressure	0.86	0.89
Goal Shot Outcome	1	0.96
Goal Shot Attack Type	1	0.92
Turnover Type	0.96	0.98
Defensive Pressure	0.87	0.90
Turnover Location	0.88	0.97
Turnover Attack Type	0.88	0.88

4.3 Data Analysis

The XML file for each game, which contained all variables recorded in chronological order, was exported from SportsCode™ (Hudl, https://www.hudl.com) and imported into and stored in Microsoft Excel™. Results were then imported into RStudio 1.3.1093 (RStudio Inc, https://www.rstudio.com) for data analysis. Each match file per team was divided based on the current match status for a given point in time; winning, losing or drawing. The total number of game actions was recorded per match per team and the percentage for each match status category calculated. To be considered for analysis, a team must have had >25% of game actions within a match status category to ensure a large enough sample of data was collected and outlying time periods removed. Data was collated and variables transformed so

they were relative to match time or spatio-temporal variables (e.g. goal shots per established attacks). Variables reported as total number of actions were divided by the proportion of game time period per match status so that variables were standardised and able to be compared. For example, 3 goal shots in 55% game time = 5.45 goal shots in 100% game time. One hundred and seventy-one variables were produced for statistical analysis.

4.4 Statistical Analysis

Statistical analysis was conducted using R (version 4.03) in RStudio. The statistical analysis procedure was completed separately on the male and female data sets to identify specific game styles per gender. Data were standardised as a z-score so variables received equal weighting when compared. Exploratory analyses were conducted and variables with near zero variance or variables contributing <2% of actions were excluded from further analysis as they were considered outliers, or made little contribution to distinguishing game styles.

The remaining 102 variables were arranged into 6 categories that reflect the different components contributing to a game style in hockey. Categories included:

1. Established Attack Game Actions: types of ball movements used during balanced attacks
2. Established Attack Success: ability of a team to get the ball to attacking positions during a balanced attack
3. Counter Attack Game Actions: types of ball movements used during unstructured attacks
4. Counter Attack Success: ability of a team to get the ball to attacking positions during an unstructured attack
5. Set Piece Occurrence: number of penalty corners or strokes awarded during a match
6. Tempo: length of possession and directness of attack

Definitions of and calculations used to create variables for each category are presented in Table 4.2. The six game style categories chosen are consistent with others identified in research that focus on attack types, game action types and tempo (Castellano & Pic, 2019; Fernandez-Navarro et al., 2016; Gollan et al., 2018; Gomez et al., 2018; Greenham et al., 2017; Lago-Penas et al., 2017).

Table 4.2 Definitions and variables used to calculate game variables used in k-means cluster analysis and their allocated game style categories

Measure	Variables and Calculations	Game Style Category
Time per area per attack type (%)	Percentage of game actions completed in each area (AC, A25, A50, D50, D25) per established and counter attacks	Established Attack Success Counter Attack Success
Attack conversion rates (%)	Percentage of possessions resulting in a goal shot, set piece or turnover for established and counter attacks or converted to an established attack for counter attacks	Established Attack Success Counter Attack Success
Game Actions rate	Number of game actions per established and counter attacks, goal shots, stoppages and turnovers	Tempo
Attacks per game	Number of established and counter attacks and set pieces per game	Tempo Set Piece
Penetrating actions per game	Number of penetrating game actions per game	Tempo
Game Actions per area per attack type (%)	Dribble, pass, through ball (A50), overhead (D50, D25), cross (A25, AC), clearance (D25), goal shot (AC) per established and counter attacks	Established Attack Game Actions Counter Attack Game Actions
Main: Gain per area per attack type	Ratio of game actions that were maintained to game actions that were gained in each area per established and counter attacks. A higher number indicates more actions before an advantage was gained	Established Attack Success Counter Attack Success
Retain: Turnover per area per attack type	Ratio of game actions that were retained to game actions that resulted in a turnover in each area per established and counter attacks. A higher number indicates longer time in possession before a turnover	Established Attack Success Counter Attack Success
Stoppages per area per attack type (%)	Stoppages per area/Total Stoppages per established and counter attacks	Established Attack Success Counter Attack Success
Restart Speed Slow: Fast per attack type	Ratio of restarting play from stoppages slowly to those taken quickly per established and counter attacks	Established Attack Success Counter Attack Success
Attacks per Goal Shot	Number of established and counter attacks before a goal shot is recorded	Established Attack Success Counter Attack Success

Table 4.2 continued

Measure	Variables and Calculations	Game Style Category
Attacks per Goal	Number of established attacks, counter attacks and set pieces before a goal is recorded	Established Attack Success Counter Attack Success Set Piece
Types of turnovers per area per attack type (%)	Stoppages: free hit, out, missed shot (AC) In Play: Tackle, intercept, missed trap, lost ball, rebound, blocked	Established Attack Success Counter Attack Success
Pressure per turnover type per area (%)	High, medium and low per established attack and counter attack	Established Attack Success Counter Attack Success
Turnovers per area per attack type (%)	Turnovers per area/Total Turnovers per established and counter attacks	Established Attack Success Counter Attack Success

A k-means clustering algorithm was used to separate the matches into clusters per category using the *'kmeans'* function from the *'stats'* R package (R Core Team, 2020). The optimal number of clusters was determined upon visual inspection of a scree plot (i.e. the elbow method) whereby the highest number of clusters that reduced the within-cluster variation substantially was identified. Bootstrapping using the *'clusterboot'* function in the *'fpc'* R package (Hennig, 2020) was performed with 100 iterations during the k-means algorithm training to assess the reliability of cluster selection. Consistent clusters were produced in at least 75% of iterations for each category.

The two clusters identified from the k-means analysis per category, representing the different game styles, were defined as follows (presented as Category: Cluster):

1. Established Attack Game Actions: Pass or Dribble
2. Established Attack Success: Strong or Poor
3. Counter Attack Game Actions: Pass or Dribble
4. Counter Attack Success: Strong or Poor
5. Set Piece Occurrence: High or Low
6. Tempo: Direct or Possession

A team's game style was determined by assessing the overall performance in each of the 6 categories. The proportion of games a team were placed in the first and second cluster for each game style category was calculated. The defensive ability of a team was also calculated

by analysing games when each team was the opposition to identify the game actions used against them when defending, how many set pieces they conceded, and the tempo played against them. Teams were also analysed for strength in established defence and counter defence; when the opposition were strong in established attack a team was poor in established defence.

Decision trees were built, using the *'rpart'* R package (Therneau & Atkinson, 2019), to predict the probability of playing a game style category (pass, dribble, strong, poor, high, low, direct, possession) based on extrinsic match context and the other 5 game style categories not included as the response variable. Extrinsic contextual variables included match status, match location, team quality, opposition quality and opposition game style. Intrinsic game factors included established attack game actions, established attack success, counter attack game actions, counter attack success, set piece occurrence and tempo. The variables with the highest importance in identifying the probabilities of playing each game style were assessed by accessing the *'variable.importance'* attribute of the rpart object.

4.5 Results

4.5.1 Game Style Variables

The mean values for each variable per cluster (game style) are presented in Figures 4.2 - 4.7. Colours represent z-scores with blue indicating above average occurrence, and red representing below average occurrence during a game. For established attack (Figure 4.2) and counter attack (Figure 4.3) game action categories, the pass cluster had a greater percentage of game actions as passes than the other cluster in each field location, while the dribble cluster had a greater percentage of dribbling actions. The strong category for established (Figure 4.4) and counter attack (Figure 4.5) success represented having greater possession in the attacking half, while the poor category had greater game events in the defensive half. Set pieces (Figure 4.6) were based on whether there was a high or low number occurring per game. The direct cluster in the tempo category (Figure 4.7) had a low number of game actions per game, and the possession cluster had a high number per game.

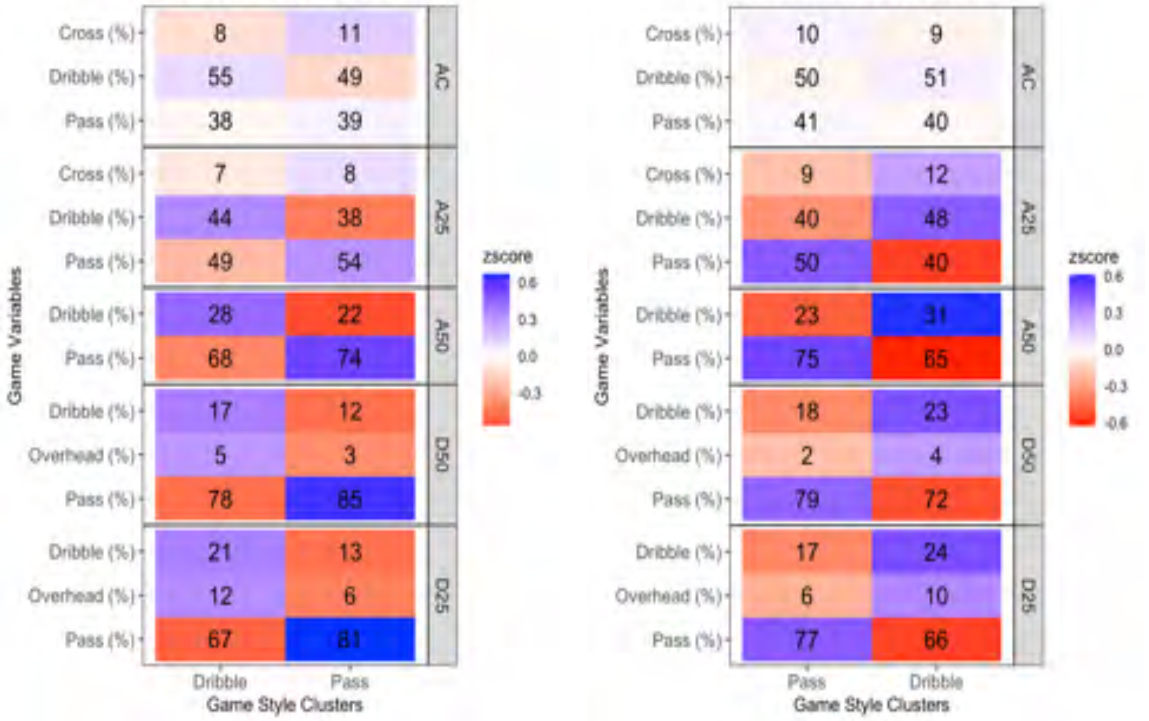


Figure 4.2 Established Attack Game Actions Game Style Category for men (left) and women (right). Results are presented as mean values for game variables per field location on the y axis for dribble and pass game style clusters on the x axis. Z-scores indicate above average (blue) and below average (red) performance compared to the league average.

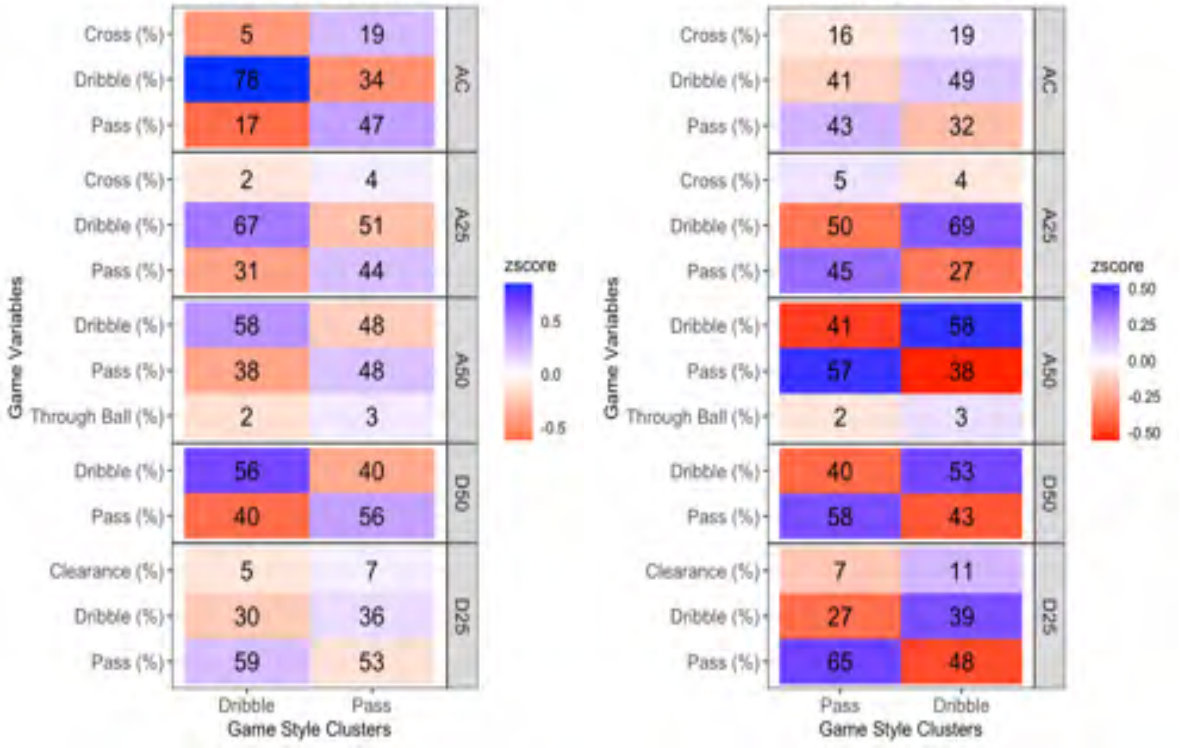


Figure 4.3 Counter Attack Game Actions Game Style Category for men (left) and women (right). Results are presented as mean values for game variables per field location on the y axis for dribble and pass game style clusters on the x axis. Z-scores indicate above average (blue) and below average (red) performance compared to the league average.

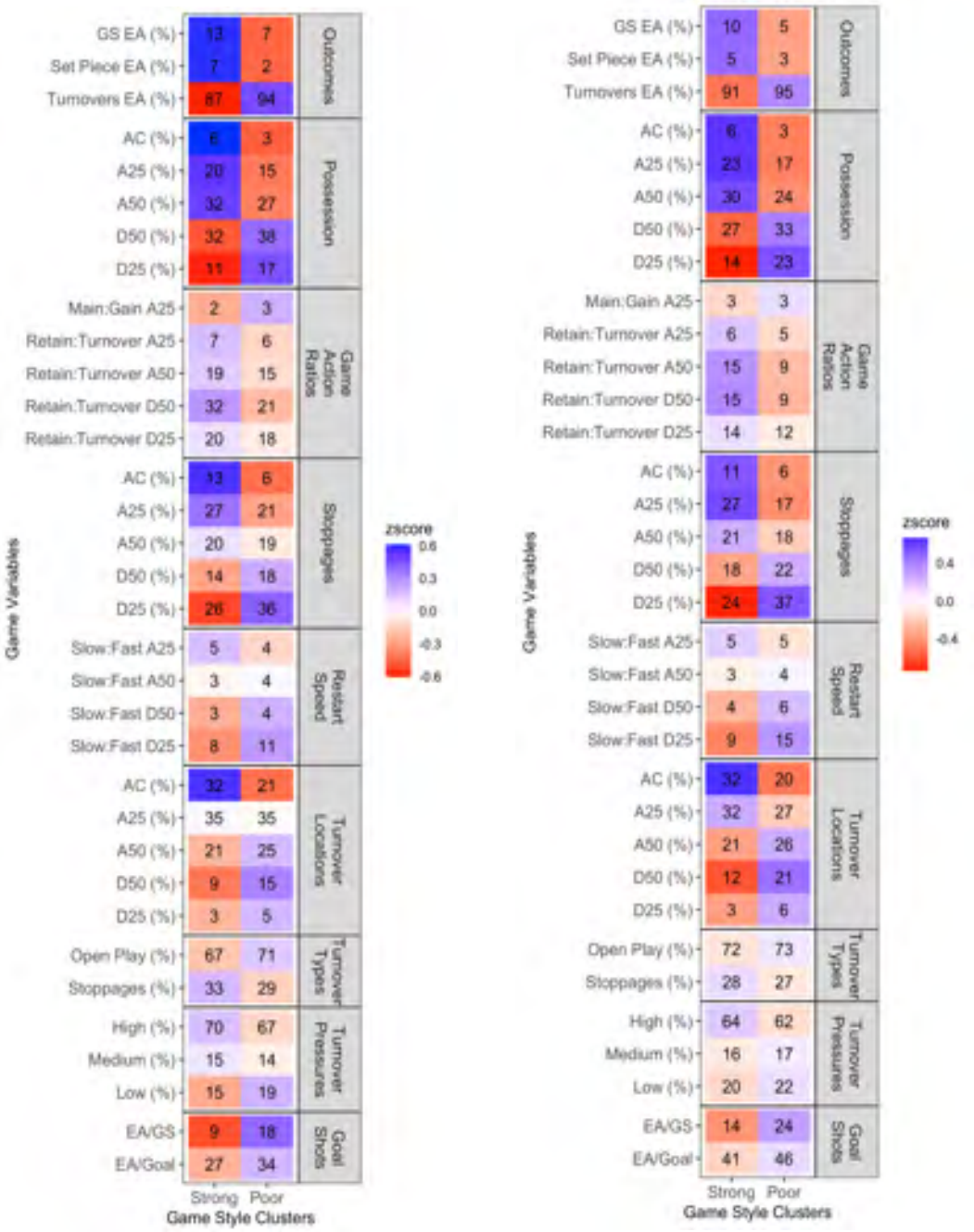


Figure 4.4 Established Attack Success Game Style Category for men (left) and women (right). Results are presented as mean values for game variables per game events on the y axis for strong and poor game style clusters on the x axis. Z-scores indicate above average (blue) and below average (red) performance compared to the league average.

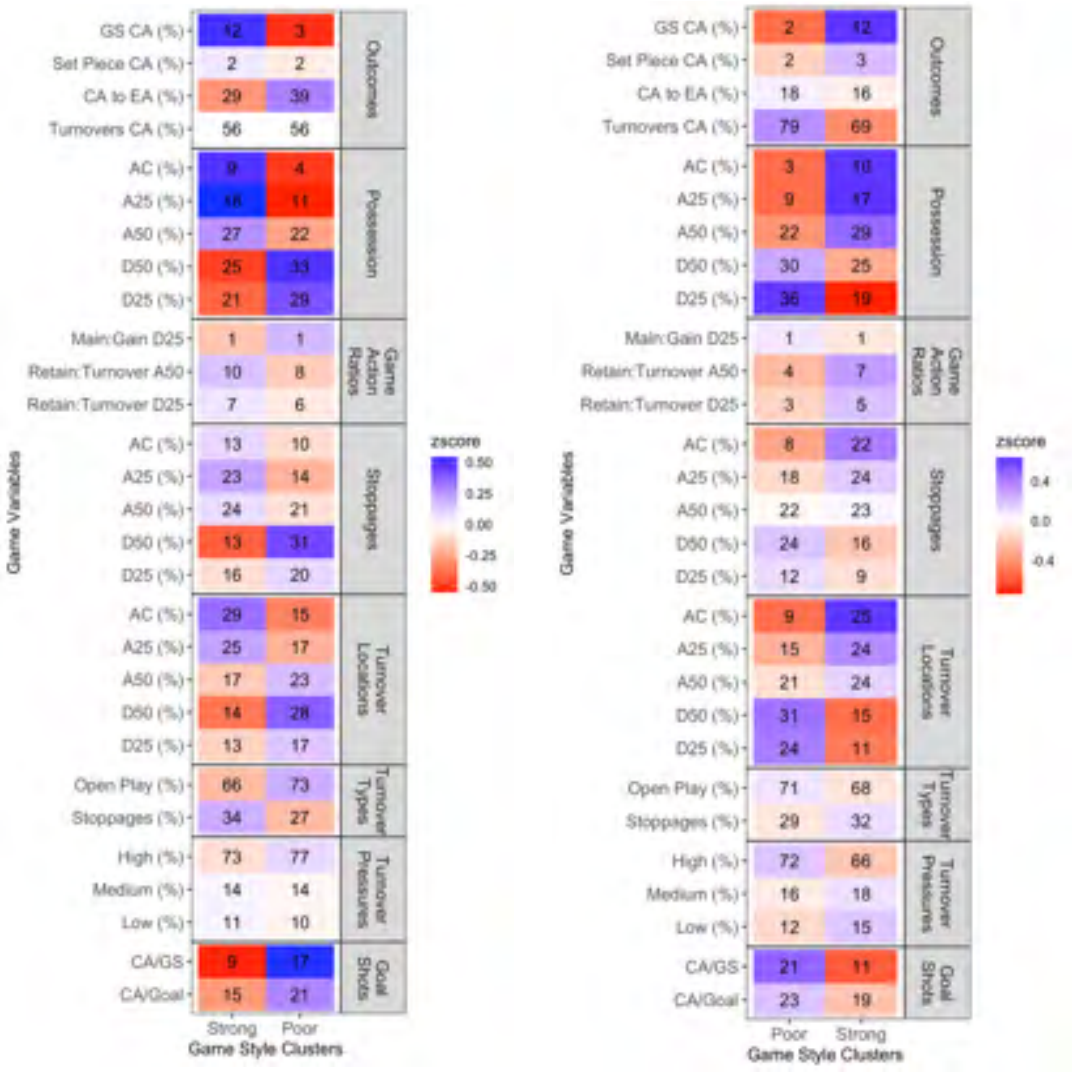


Figure 4.5 Counter Attack Success Game Style Category for men (left) and women (right). Results are presented as mean values for game variables per game events on the y axis for strong and poor game style clusters on the x axis. Z-scores indicate above average (blue) and below average (red) performance compared to the league average.

Figure 4.6 Set Piece Occurrence Game Style Category for men (left) and women (right). Results are presented as mean values for game variables on the y axis for high and low game style clusters on the x axis. Z-scores indicate above average (blue) and below average (red) performance compared to the league average.

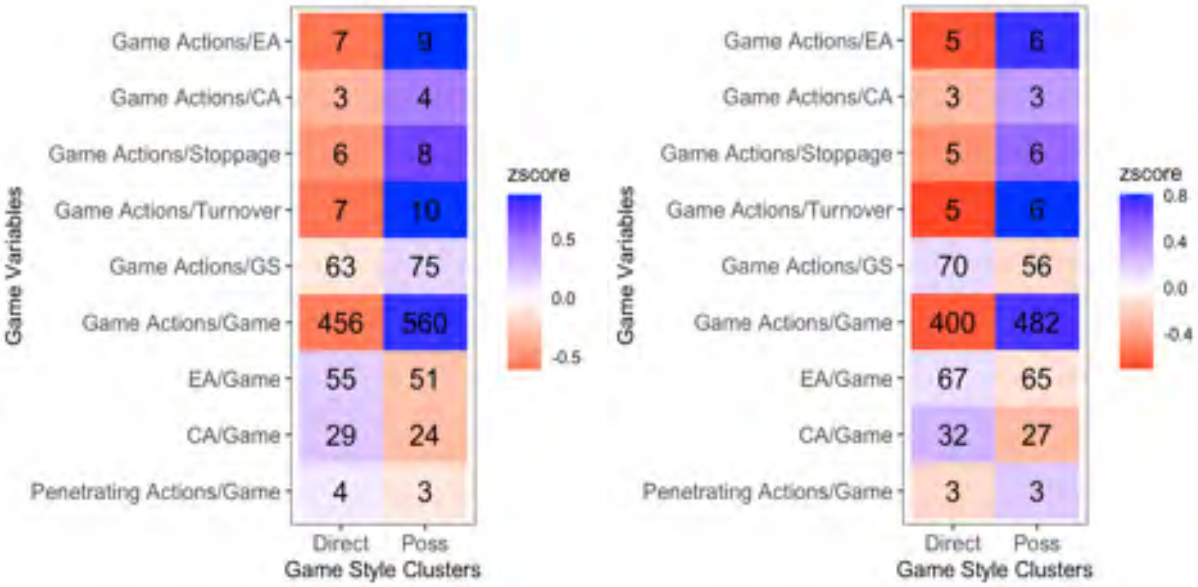


Figure 4.7 Tempo Game Style Category for men (left) and women (right). Results are presented as mean values for game variables on the y axis for direct and possession game style clusters on the x axis. Z-scores indicate above average (blue) and below average (red) performance compared to the league average.

4.5.2 Team Game Styles

The percentage of games in which a team was placed in the first or second cluster for each game style category for men and women is displayed in Supplementary Resource 4.4 and 4.5 respectively. Green indicates a game style used in a high percentage of games and red a low percentage of games. Example team profiles are illustrated in Table 4.3 for Australia and Netherlands women's teams. For example, when Australia were winning, they were placed in the dribble cluster for established attacks for 22% of games, and they were placed in the pass cluster for 78% of games. The combination of all attacking and defensive variables reflects a team's game style.

4.5.3 Decision Trees

Decision trees illustrating the influence of extrinsic and intrinsic factors on the probability of playing a game style category for men and women are displayed in Supplementary Resources 4.6 - 4.17. For men, match status and tempo were the most important variables in determining established attack game actions. Set piece occurrence and established attack success had the greatest effect on determining the other category type. Counter attack game actions were determined by match status and opposition strength in established attacks. Counter attack success was determined by opposition strength in established attacks and counter attack game actions, and tempo was largely impacted by team quality and established attack game actions.

For women, established attack game actions and counter attack game actions were the variables with the greatest importance in determining the other category. Opposition strength in counter attacks had the greatest influence on established attack success, similarly counter attack success was determined by opposition strength in established attacks. Opposition established attack game actions and established attack success had the greatest impact on set pieces. Counter attack success was the most important variable when determining a team's tempo.

Table 4.3 Game Styles for Australia and Netherlands women's teams when winning (W), losing (L) and drawing (D). Results are presented as the percentage of games a team was allocated to each game style category from the k-means cluster analysis. Green represents game styles a team implements consistently, red represents a game style that is rarely used.

		Australia			Netherlands		
Game Style Category	Clusters	W	L	D	W	L	D
Established Attack Game Actions	Dribble	22	0	0	21	0	0
	Pass	78	100	100	79	100	100
Established Attack Success	Strong	11	57	25	57	100	91
	Poor	89	43	75	43	0	9
Counter Attack Game Actions	Dribble	22	43	25	21	50	27
	Pass	78	57	75	79	50	73
Counter Attack Success	Strong	56	57	17	50	100	82
	Poor	44	43	83	50	0	18
Set Piece Occurrence	High	22	57	25	50	0	45
	Low	78	43	75	50	100	55
Tempo	Direct	78	71	67	7	0	18
	Possession	22	29	33	93	100	82
Opposition Established Attack Game Actions	Dribble	56	57	46	57	50	45
	Pass	44	43	54	43	50	55
Established Defence	Strong	22	43	38	79	100	100
	Poor	78	57	62	21	0	0
Opposition Counter Attack Game Actions	Dribble	78	71	46	50	50	55
	Pass	22	29	54	50	50	45
Counter Defence	Strong	33	43	23	86	100	100
	Poor	67	57	77	14	0	0
Opposition Set Piece Occurrence	High	56	43	38	29	0	27
	Low	44	57	62	71	100	73
Opposition Tempo	Direct	33	71	38	64	100	82
	Possession	67	29	62	36	0	18

4.6 Discussion

The aims of this research were to identify game styles in hockey based on the clustering of similar dynamic game actions, and assess the influence of extrinsic contextual and intrinsic game factors on the probability of a game style being played under different match conditions. Game styles include ‘passing’ and ‘dribbling’ types for established and counter attack game actions, ‘strong’ or ‘poor’ for established and counter attack success, ‘high’ and ‘low’ for set piece occurrence, and ‘direct’ or ‘possession’ styles for tempo. Opposition game style and other reference team game styles had the greatest influence on determining the probability of playing each game style type. This analysis provides practical insights into the game style teams used in international hockey, using a novel method that can be completed with the resources available in the field. The outcomes should be useful for a coach to evaluate and develop specific strategies for each situation based on the strengths and weaknesses of each team.

Men and women displayed similar results for the cluster analysis as two clusters were chosen to represent the basic strategies of play. The tempo category provided the main difference between the male and female teams, as male teams created more goal scoring opportunities using a direct style, while women created more opportunities using a possession-orientated style. An earlier study identified a straight shot from the top, compared to a deflection close to goal, was the most effective strategy for men and women respectively to score from a penalty corner (Pinero et al., 2007). It is important to analyse genders separately to identify specific strategies that reflect the abilities of the players. The physical abilities will determine strategy as a coach can only develop a successful strategy based on the players within a team.

Decision trees highlighted the dynamic, complex nature of hockey by identifying the multitude of extrinsic and intrinsic factors that influence the way a team plays. However, decision trees were also used to identify which factors have the greatest influence on the probability of playing a particular game style so a coach can plan for different situations. For the female teams, established attack success was influenced by opposition counter attack success. A team was over 4 times more likely to be poor in established attack if the opposition was strong in counter attack. It appears that if the opposition was strong in counter attacks, they tended to turn the ball over in their attacking half. Consequently, the reference team will have to begin their established attack from their defensive half, and attempt to penetrate an organised defence over a greater distance of the field. Alternatively, if the opposition turn the ball over in their defensive half, a team commences their possession from

an attacking position providing a higher chance at creating a positive outcome from the play. There is less time and space for the defence to recover if they become imbalanced. A similar pattern was found in soccer, where a team was more likely to create a goal scoring opportunity starting from the final third, compared to the defensive third, against a balanced defence (Tenga et al., 2010b). The likelihood of a circle entry occurring in hockey increased as the distance between the player passing the ball and the goal and player receiving the ball decreased (McInerney, 2017). Beginning an attack from the attacking half provides more favourable conditions to execute this strategy. These outcomes illustrate the importance of analysing the influence of the opposition, or a team's defensive profile, as a strong attack stems from a strong defence.

Comparatively, in male hockey, a team was 4.5 times more likely to be strong in established attack if they had a high number of set pieces. However, a team would only achieve a high number of set pieces if they were strong in established attack. A similar study showed that one game style in soccer was based on strong performances in established attacks and set pieces reflecting the link between these two game style categories (Gollan et al., 2020). In soccer, a goal scoring opportunity was more likely to be produced from a long possession (>5 passes), compared to short (1-2 passes), against a balanced defence (Tenga et al., 2010a). Thus, a team cannot create goal scoring opportunities from set pieces, or open play, unless they are able to get and maintain the ball in the attacking areas of the field. Set pieces are more likely to be awarded from established attacks when there are high numbers of players within the circle. When a goal scoring opportunity cannot be created from open-play, winning a penalty corner may be considered the next best option. Teams may also prefer an attempt at a set piece over a goal shot in established attack as it provides a more advantageous situation to score. This is due to the defensive team being restricted to 4 outfield players and a goalkeeper, while the attacking team are not limited and are able to attempt a rehearsed play. A previous investigation found that more than half of goals scored in international hockey for both men and women were from set pieces, as opposed to open play (Pineiro et al., 2006), highlighting the importance of this attack type.

Counter attacks involve a transition period where the attacking team attempt to penetrate the defence immediately while the defence attempt to reorganise their team structure. Counter attacks can be an effective strategy to create goal scoring opportunities by capitalising on imbalances in the defence (Tenga et al., 2010b). Counter attack success for both men and women was influenced by opposition strength in established attack. A team was up to 4 times

more likely to be poor in counter attacks if the opposition was strong in established attacks. When the ball is turned over from an established attack in the attacking half, especially in the A25, there is likely a large number of attackers and defenders around the ball. This pattern arises as teams compress the players into the attacking half as the defence protect their goal, and the attackers attempt to keep the ball from leaving this crucial area (Alexander et al., 2019b). Consequently, there is limited space to move into when trying to counter attack allowing the defence to apply immediate pressure on the ball carrier. In soccer, pressuring the ball carrier reduces the likelihood of a goal scoring opportunity occurring by a factor of 3 (Gonzalez-Rodenas et al., 2016). However, when a team is poor in established attack, they tend to turn the ball over in their defensive half, and have less players protecting their own goal. This scenario arises as there is a greater spread of players along the length of the field, and a temporary disconnect between the defenders, midfielders and strikers. Consequently, there is extra space for the opposition to move the ball into and create more 1v1 dribbling challenges during this transition period until additional players arrive. An early study showed that a goal was more likely to be scored in international women's hockey when the ball was repossessed in the attacking half, and the entry into the circle was by dribbling (Sunderland et al., 2006). Coaches should be recognisant of a strong defence precedes a strong attack by regaining the ball in attacking positions.

As was shown in penalty corners, the physical capabilities of the players in a team will determine what game actions they use in open play (Pineiro et al., 2007). For example, strength will affect the ability to control the ball, speed will determine the ability to out run an opponent while dribbling, and power will influence the length and speed of passes. These capabilities consequently influence the strategy and intent of a team to attack, maintain possession or play defensively in different situations. In the female teams, game actions used in established attacks were related to those used in counter attacks. A team was approximately twice as likely to pass in established attacks if they dribbled in counter attacks and vice versa. Match status, or team quality, did not distinguish which game actions a team favoured, implying that being classed as dribbling or passing game style type did not influence the success of a team. Similar results have been identified in rugby union where use of different game actions were successful for different teams (Croft et al., 2015). In hockey, both dribbling and passing actions can be used offensively to manipulate the defence and create space, or defensively to maintain possession and protect their goal. These options reinforce the notion there is more than one way to win a game, and international teams should have strategies that are specific to the abilities of the players in their team.

The concept of multiple options or strategies can also be observed in determining the tempo game style, as the specific abilities of players will determine their ability to control possession. For male teams, established attack game actions and team quality were the major influencing factors on tempo. The top men's teams were 3.5 times more likely than bottom-ranked teams to play a possession style if they used passes in established attack. In contrast, bottom-ranked teams were 6 times more likely to play a direct, than possession style, when they used passes. Playing direct indicates that a team looks to find the shortest or quickest path to goal, and using longer passes allows a team to cover a larger part of the ground quicker. Whereas a team looking to control the game by maintaining possession may play passively, keeping the ball away from the opposition by using shorter passes around the midfield and backs, until an opportunity to attack arises. Top teams are more successful at retaining possession for longer periods than bottom teams (Lago, 2009; Tenga & Sigmundstad, 2011) reflecting a bottom team's likelihood to play direct. The offensive intent of a team is revealed by analysing the interaction between game actions and tempo, as it highlights how and where a team moves the ball and their ability to engage with the defence, which would not be apparent by studying either game style category on their own.

For female teams, tempo was determined by a team's strength in counter attacks which similarly shows a team's ability to control possession. A team was twice as likely to play a possession style if they were strong in counter attacks, and play a direct style if they were poor in counter attacks. A strong counter attack reflects the ability to gain ground from a defensive position into an attacking one or create a goal shot from an attacking position. Thus, possession and strong counter attack game styles are linked as they reflect the ability of a team to control possession and only counter attack when appropriate opportunities arise, such as when there is space to move into (Alexander et al., 2019a) and a numerical advantage can be gained (Vilar et al., 2013). Results in soccer have illustrated that top ranked teams, compared to bottom ranked teams, were more likely to score from a counter attack, possession with 0-4 passes, or starting in the midfield (Tenga & Sigmundstad, 2011). This outcome suggested top ranked teams were better at creating opportunities and capitalising on imbalances in the defence. Comparatively, teams playing a direct style are linked to poor counter attack performance as they attempt to counter attack from all positions on the field. For example, counter attacking from the D25 under high pressure situations when they are unlikely to gain ground quickly as the opposition has numbers in front of the ball. Lower ranked soccer teams were more likely to use direct play, and less likely to use maintenance,

build up and sustained threat play which involves controlled possession within different zones of the field (Fernandez-Navarro et al., 2018). A team's inability to hold on to possession under pressure reflects their intent to attack directly given it provides the best opportunity for them to score.

Analysing the interaction of game style categories allows an analyst to gain practical insights into performance as common strategies can be identified. For example, if a team uses a possession approach, but has poor attacking position in established and counter attacks, they are likely to also employ a maintenance strategy, preventing the opposition scoring by not letting them have the ball. When a team is playing direct and has poor attacking position, they are more likely under high pressure and aim to win, or not lose, by protecting their goal. If a team is playing direct but has a strong attacking position, they are able to progress the ball quickly from defence by playing at a high intensity. On the other hand, using a possession approach in a strong attacking position implies a team has repeat opportunities at goal constantly applying high pressure. These relationships reinforce the notion that there is more than one way to win, and all game style categories must be considered to understand what strategies a team is using.

This study developed game style profiles to highlight the consistent strategies a team uses so an analyst can identify a team's strengths and weaknesses, and likely plan of attack. By comparing teams, we can also show how different strategies can be successful. The Netherlands and Australia women's teams whom were placed 1st and 2nd respectively in the 2019 Pro League are compared as an example in Table 4.3. In attack, Australia preferred to pass and play direct in all match situations, but were poor in established attack, had low set pieces especially when winning or drawing, and were poor in counter attacks when drawing. However, they were more likely to be strong in established and counter attacks, and had high set pieces when losing. Defensively, they were also poor in established and counter defence when winning or drawing, and average when losing but conceded a low amount of set pieces when drawing. The opposition were likely to play a possession approach against Australia when they were winning, and direct when they were losing. Australia conceded possession and territory, and focused on protecting their goal when ahead or drawing, however they also had the ability to increase pressure and intensity when losing to "get back into" games.

The Netherlands also preferred passing to dribbling but used a possession approach to control the game. They were strong in established and counter attacks especially when losing and

drawing, but strong in defence in all match situations, forced opposition teams to play direct, and did not concede a high number of set pieces. Thus, the Dutch maximised their goal scoring opportunities and minimised the opposition's, reflecting the limited goals scored against them and match periods when losing. These differing yet successful strategies reflect results in Australian Rules Football, teams with similar profiles of performance indicators had different match outcomes, and different performance indicators were more important in determining success for different teams (Spencer et al., 2016). Collectively, these outcomes in invasion sports reinforce the idea that teams must be analysed individually, and coaches should implement strategies that reflect the players strengths in their team. Future research should also analyse the impact of individual players within a team, and identify how different player styles impacts a team's game style. A limitation of this study is that all teams are within the top ranked FIH teams which may have masked the effect of match status or team quality on game styles. Future research may analyse future tournaments with a wider range of team quality to clarify game styles types and the effect of match context on performance.

In conclusion, a performance analysis process has been outlined that involves capturing detailed game information, using video and notational analysis, and simplifying it to game style categories using a clustering technique to reflect the way strategies are employed in practice. Game style profiles have been created to highlight the strengths and weaknesses of individual teams. Decision trees have been used to reveal the probabilities of playing a game style based on extrinsic contextual and intrinsic game factors. These results provide practical insight into strategy in hockey by identifying how and where a team moves the ball to create the best outcomes under different match situations.

4.7 References

1. Alexander, J.P., Spencer, B., Mara, J.K., & Robertson, S. (2019a). Collective team behaviour of Australian Rules football during phases of match play. *Journal of Sports Sciences,* 37(3), 237-243.
2. Alexander, J.P., Spencer, B., Sweeting, A.J., Mara, J.K., & Robertson, S. (2019b). The influence of match phase and field position on collective team behaviour in Australian Rules football. *Journal of Sports Sciences,* 37(2), 1699-1707.
3. Altman, D.G. (1991). *Practical Statistics for Medical Research*. London: Chapman & Hall, p 404.
4. Castellano, J., & Pic, M. (2019). Identification and preference of game styles in LaLiga associated with match outcomes. *International Journal of Environmental Research and Public Health,* 16(24), 5090.
5. Croft, H., Lamb, P., & Middlemas, S. (2015). The application of self-organising maps to performance analysis data in rugby union. *International Journal of Performance Analysis in Sport,* 15(3), 1037-1046.
6. Croft, H., Willcox, B., & Lamb, P. (2017). Using performance data to identify styles of play in netball: An alternative to performance indicators. *International Journal of Performance Analysis in Sport,* 17(6), 1034-1043.
7. Fernandez-Navarro, J., Fradua, L., Zubillaga, A., Ford, P.R., & McRobert, A.P. (2016). Attacking and defensive styles of play in soccer: analysis of Spanish and English elite teams. *Journal of Sports Sciences,* 34(24), 2195-2204.
8. Fernandez-Navarro, J., Fradua, L., Zubillaga, A., & McRobert, A.P. (2018). Influence of contextual variables on styles of play in soccer. *International Journal of Performance Analysis in Sport,* 18(3), 423-436.
9. Gollan S, Bellenger, C., & Norton, K. (2020). Contextual factors impact styles of play in the English Premier League. *Journal of Sports Science & Medicine,* 19(1), 78-83.
10. Gollan, S., Ferrar, K., & Norton, K. (2018). Characterising game styles in the English Premier League using the "moments of play" framework. *International Journal of Performance Analysis in Sport,* 18(6), 998-1009.
11. Gómez, M.-Á., Mitrotasios, M., Armatas, V., & Lago-Penas, C. (2018). Analysis of playing styles according to team quality and match location in Greek professional soccer. *International Journal of Performance Analysis in Sport* 18(6), 986-997.
12. Gonzalez-Rodenas, J., Lopez-Bondia, I., Calabuig, F., Perez-Turpin, J.A., & Aranda, R. (2016). Association between playing tactics and creating scoring opportunities in

counterattacks from United States Major League Soccer games. *International Journal of Performance Analysis in Sport,* 16(2), 737-752.

13. González-Ródenas, J, Aranda, R., & Aranda-Malaves, R. (2021). The effect of contextual variables on the attacking style of play in professional soccer. *Journal of Human Sport & Exercise,* 16(2), 399-410.
14. Greenham, G., Hewitt, A., & Norton, K. (2017). A pilot study to measure game style within Australian football. *International Journal of Performance Analysis in Sport,* 17(4), 576-585.
15. Gréhaigne, J.-F., Godbout, P., & Bouthier, D. (1999). The foundations of tactics and strategy in team sports. *Journal of Teaching in Physical Education,* 18(2), 159-174.
16. Hennig, C. (2020). fpc: Flexible Procedures for Clustering. R package version 2.2-9.
17. Hewitt, A., Greenham, G., & Norton, K. (2016). Game style in soccer: What is it and can we quantify it? *International Journal of Performance Analysis in Sport,* 16(1), 355-372.
18. Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences,* 27(13), 1463-1469.
19. Lago-Penas, C., Gomez-Ruano, M., & Yang, G. (2017). Styles of play in professional soccer: An approach of the Chinese Soccer Super League. *International Journal of Performance Analysis in Sport,* 17(6), 1073-1084.
20. Lord, F., Pyne, D.B., Welvaert, M., & Mara, J.K. (2020). Methods of performance analysis in team invasion sports: A systematic review. *Journal of Sports Sciences,* 38(20), 2338-2349.
21. Lord, F., Pyne, D.B., Welvaert, M., & Mara, J.K. (2022). Field hockey from the performance analyst's perspective: A systematic review. *International Journal of Sports Science & Coaching,* 17(1), 220-232.
22. McInerney, C. (2017). Determining spatio-temporal metrics that distinguish play outcomes in field hockey. Sheffield Hallam University (United Kingdom).
23. Piñeiro, R., Sampedro, J., & Refoyo, I. (2006). Strategy analysis in high performance field hockey. *International Congress of Sport Sciences.* Pontevedra, 4-6 May.
24. Piñeiro, R., Molinuevo, J.S., & Román, I.R. (2007). Differences between international men's and women's teams in the strategic action of the penalty corner in field hockey. *International Journal of Performance Analysis in Sport,* 7(3), 67-83.
25. R Core Team. (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

26. Ribeiro, J., Davids, K., Araújo, D., Silva, P., Ramos, J., Lopes, R., & Garganta, J. (2019). The role of hypernetworks as a multilevel methodology for modelling and understanding dynamics of team sports performance. *Sports Medicine,* 49(9), 1337-1344.
27. Ribeiro, J., Silva, P., Duarte, R., Davids, K., & Garganta, J. (2017). Team sports performance analysed through the lens of social network theory: Implications for research and practice. *Sports Medicine,* 47(9), 1689-1696.
28. Soltanzadeh, S., & Mooney, M. (2016). Systems thinking and team performance analysis. *International Sport Coaching Journal,* 3(2), 184-191.
29. Spencer, B., Morgan, S., Zeleznikow, J., & Robertson, S. (2016). Clustering team profiles in the Australian Football League using performance indicators. *Proceedings of the 13th Australasian Conference on Mathematics and Computers in Sport,* Melbourne.
30. Sunderland, C., Bussell, C., Atkinson, G., Alltree, R., & Kates, M. (2006). Patterns of play and goals scored in international standard women's field-hockey. *International Journal of Performance Analysis in Sport,* 6(1), 13-29.
31. Tenga, A., Holme, I., Ronglan, L.T., & Bahr, R. (2010a). Effect of playing tactics on achieving score-box possessions in a random series of team possessions from Norwegian professional soccer matches. *Journal of Sports Sciences,* 28(3), 245-255.
32. Tenga, A., Ronglan, L.T., & Bahr, R. (2010b). Measuring the effectiveness of offensive match-play in professional soccer. *European Journal of Sport Science,* 10(4), 269-277.
33. Tenga, A., & Sigmundstad, E. (2011). Characteristics of goal-scoring possessions in open play: Comparing the top, in-between and bottom teams from professional soccer league. *International Journal of Performance Analysis in Sport,* 11(3), 545-552.
34. Therneau, T., & Atkinson, B. (2019). rpart: Recursive Partitioning and Regression Trees. R package version 4.1-15.
35. Vilar, L., Araujo, D., Davids, K., & Bar-Yam, Y. (2013). Science of winning soccer: Emergent pattern-forming dynamics in association football. *Journal of Systems Science & Complexity,* 26(1), 73-84.

4.8 Supplementary Resources

Supplementary Resource 4.1 Notational analysis categories and definitions

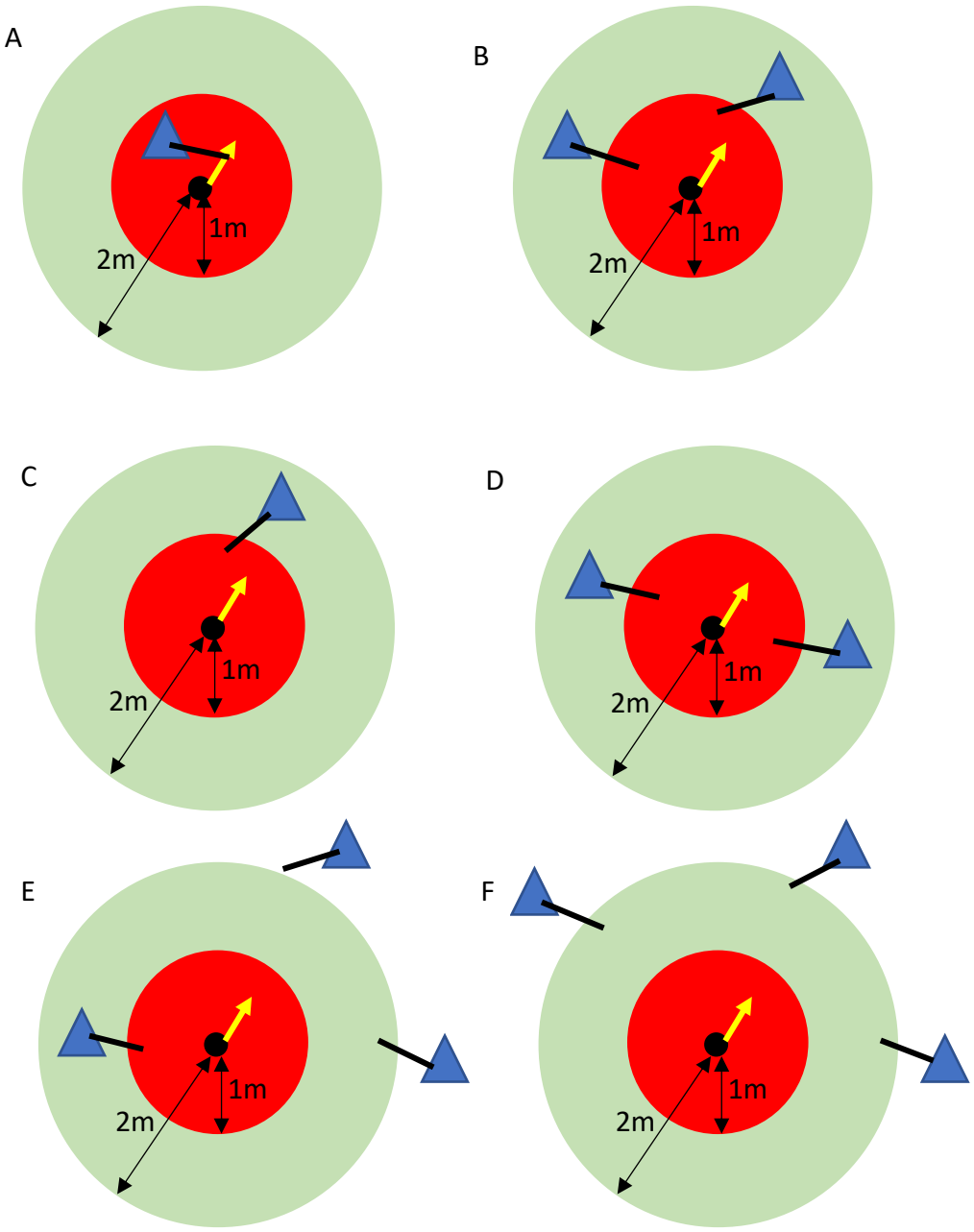
Category	Variable	Definition
Attack Type	Established Attack	Attacking team has a high degree of control over the possession, generally commencing from a dead ball situation. Both attacking and defensive team structures are balanced. Progression of the attack is slower, involving a high number of passes which don't attempt to penetrate the defence immediately. An established attack ends when possession is lost, or a set piece is awarded.
	Counter Attack	Transition from defence to attack from a turnover in open play or playing on immediately from a dead ball situation. Unorganised or imbalanced attacking and defensive structures, with the attacking team attempting to exploit the space left open by the oppositions attack. Movement of the ball is fast and attempts to penetrate the defence immediately. A counter attack ends when a break down in play occurs such as free hit or ball out of play, allowing time to reorganise team structure. In this case, the attack is now considered an established attack.
	Set Piece	Penalty corner or stroke, where the control of the ball is exclusively with one team. A set piece for a penalty corner is considered over after the initial goal shot has been taken. If the shot is saved any rebound play is considered as established attack. A set piece for a penalty stroke only contains the one goal shot, the opposition regain possession as a centre pass if a goal is scored or as a 16 if the ball is saved or off target.
Game Actions	Dribble	The attacker controls the ball by moving it close to the stick and individually attempts to gain ground or beat an opponent.
	Pass	The ball is attempted to be transferred between two attackers in a push, flick, hit or sweep motion.
	Through Ball	The ball is played from one attacker into space for another attacker to attempt to run on to.
	Overhead	An attempted lifted pass between two attackers that travels above the heads of players.
	Cross	The ball is attempted to be transferred into the circle towards or across the face of goal searching for a deflection to goal or penalty corner.
	Clearance	The ball is played out by the attacker to space in the defensive 25 in an attempt to remove the ball from the danger zone.
	Goal Shot	The ball is played deliberately towards goal in a hit, sweep, push or flick motion.
Movement Effect	Penetrating	Movement of ball creates a high percentage goal scoring opportunity by moving the ball close to goal where a numerical advantage is gained, or the defender is moved out of position and is unable to prevent a goal shot.
	Gain	Movement of ball gains territory that is advantageous to the attackers by moving towards the direction of the goal and eliminating a defender.
	Maintain	Attacking team remain in possession but do not gain an advantage, ball movement is generally backwards or sideways, or ground is gained without eliminating a defender.

Supplementary Resource 4.1 continued

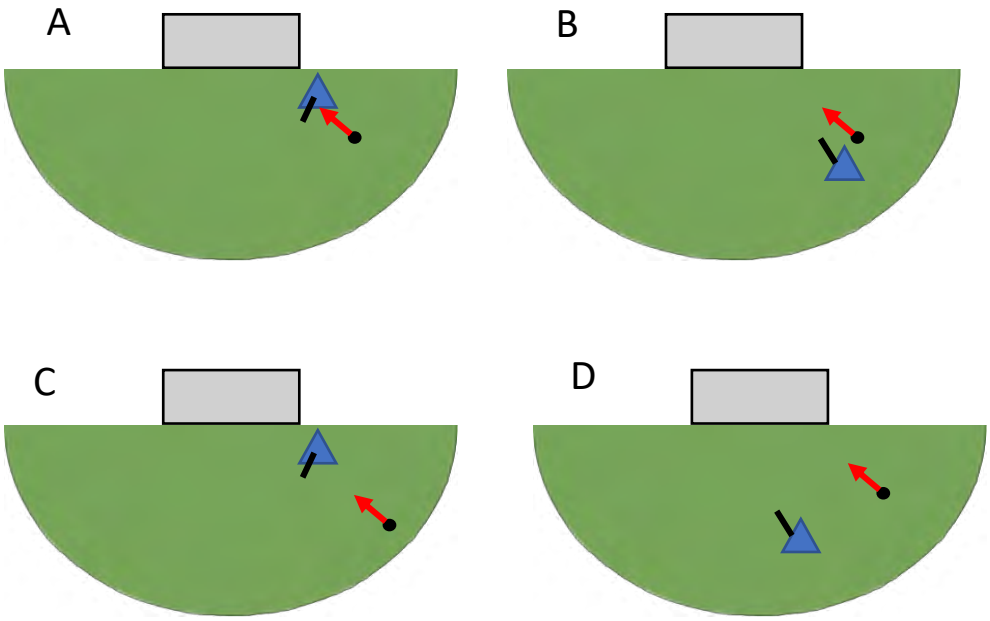
Category	Variable	Definition
	Turnover	Movement of the ball disadvantages the player with the ball or their team mates resulting in a turnover.
Stoppages	Sideline	Ball is played out of bounds over the sideline. The team that did not touch the ball last restarts possession from the sideline where the ball crossed the line.
	16	Ball is played over the backline outside the goals by the attacking team. The opposition restart possession from the 16-yard line in line with where the ball went out.
	Long Corner	The defensive team are the last team to touch the ball before it is played over the backline in their defensive 25. Attacking team restart play from the 25-yard line in line with where the ball was played out.
	Free Hit	Any illegal move in the field of play but outside the circle. The attacking team restart play from the location of the error.
	Penalty Corner	Any illegal play in the circle or in the attacking 25 that is deemed to obstruct a probable goal scoring opportunity.
	Penalty Stroke	Any illegal play in the circle that prevents a probable goal scoring opportunity.
Stoppages Restart Speed	Fast	Ball is played on immediately from a stoppage before the opposition has reorganised their defensive structure.
	Slow	There is a pause in play after a stoppage is awarded allowing the defensive team to reorganise their team structure.
Turnover Type	Tackle	A defender successfully takes clean possession of the ball with their stick from an attacker dribbling the ball.
	Intercept	A pass is intercepted by the defender due to a poor or misdirected pass.
	Out	Ball is played out of bounds by the attacker due to a poor or misdirected pass.
	Free Hit	Illegal play from the attacker such as the ball touching the feet, ball played dangerously high, or obstructing the defender from reaching the ball, resulting in a free hit for the opposition.
	Lost Ball	Attacker loses control of the ball when dribbling under passive defensive pressure.
	Miss Trap	A pass is directed to another attacker and the receiving player either miss traps the ball and it rolls out of bounds or is deflected to the opposition.
	Missed Shot	A goal shot is off target crossing the backline outside the goal posts.
	Blocked	The ball is attempted to be passed to another attacker but instead is hit straight into the defenders planted stick and the ball is trapped or deflected and regained by the opposition.
	Rebound	A goal shot is saved and the deflection is regained by the opposition.
Defensive Pressure	High	Active pressure is applied by at least one defender within a 1m radius of the attacker (defender is within a hockey stick's length of the ball and contact can easily be made) (Supplementary Resource 4.2A) or passive pressure by two or more defenders within a 2m radius of the ball

Supplementary Resource 4.1 continued

Category	Variable	Definition
		(defender is within reach of the ball if they fully extend arm and stick) with one defender applying pressure from in front of the ball (Supplementary Resource 4.2B) when the turnover occurs.
	Medium	Passive pressure applied by at least one defender within a 2m radius of the attacker in front of the ball (Supplementary Resource 4.2C) or at least 2 defenders within a 2m radius but not in the direction of the ball movement (Supplementary Resource 4.2D) when the turnover occurs.
	Low	One defender is within a 2m radius not in the direction of the ball movement (Supplementary Resource 4.2E) or no defender is within a 2m radius of the attacker (defender cannot reach the ball without changing position) (Supplementary Resource 4.2F) when the turnover occurs.
Goal Shot Pressure	High	A defender is within reaching distance of the ball and able to influence the attackers goal shot by placing their stick between the ball and the goal (Supplementary Resource 4.3A).
	Medium	A defender applies pressure from the side or behind the attacker with the ball (Supplementary Resource 4.3B) or pressure is applied from in front of the attacker between 1 and 2m away (Supplementary Resource 4.3C).
	Low	Attacker is allowed a free shot at goal, no defender (other than goal keeper) attempts to stop the shot (Supplementary Resource 4.3D).
Goal Shot Outcomes	Goal	Ball is played over the backline within the goal posts.
	Saved	Ball is stopped or deflected by a defender preventing it entering the goal.
	Smothered	Ball is stopped from moving towards goal by a defender by either changing the trajectory of the ball immediately after the goal shot or blocking its movement completely.
	Turnover	Possession lost due to a goal shot that is off target and is played out of bounds or a free hit is awarded due to illegal play during the goal shot.



Supplementary Resource 4.2 Examples of defensive pressure situations. The black dot represents the attacking player with the ball, yellow arrow illustrates direction of ball movement, blue triangles represent the defenders and black lines represent the defender's hockey sticks. Figures A and B are High Pressure, C and D are Medium Pressure and E and F are Low Pressure.



Supplementary Resource 4.3 Examples of goal shot pressure situations. Black dots represent the attacking player with the ball, red arrow illustrates the trajectory of the ball, blue triangles represent the defenders and black lines represent the defender's hockey stick. Figure A illustrates a high pressure situation, Figure B and C represent medium pressure situations and Figure D displays a low pressure situation.

Supplementary Resource 4.4 Game Styles for Men's Teams when winning, losing and drawing. Results are presented as the percentage of games a team was allocated to each game style category from the k-means cluster analysis. Green represents game styles a team implements consistently, red represents a game style that is rarely used.

Team	MS	Dr EA	Pa EA	S EA	Po EA	Dr CA	Pa CA	S CA	Po CA	H SP	L SP	Dir	Poss	Opp Dr EA	Opp Pa EA	S ED	Po ED	Opp Dr CA	Opp Pa CA	S CD	Po CD	Opp H SP	Opp L SP	Opp Dir	Opp Poss
Arg	W	100	0	0	100	33	67	33	67	33	67	100	0	33	67	33	67	0	100	100	0	67	33	67	33
	L	75	25	63	38	75	25	50	50	38	63	100	0	63	38	63	38	0	100	75	25	25	75	50	50
	D	40	60	60	40	60	40	60	40	0	100	100	0	17	83	50	50	17	83	17	83	33	67	17	83
Aus	W	64	36	50	50	39	71	29	71	29	71	79	21	73	27	60	40	33	67	40	60	47	53	73	27
	L	100	0	100	0	0	100	33	67	100	0	67	33	100	0	50	50	0	100	50	50	0	100	0	100
	D	40	60	70	30	20	80	60	40	20	80	70	30	71	29	86	14	57	43	43	57	14	86	57	43
Bel	W	42	58	58	42	17	83	58	42	33	67	33	67	58	42	58	42	50	50	75	25	17	83	75	25
	L	67	33	67	33	17	83	67	33	67	33	33	67	100	0	67	33	50	50	50	50	17	83	100	0
	D	56	44	56	44	44	56	89	11	11	89	33	67	67	33	78	22	33	67	67	33	22	78	78	22
GB	W	86	14	14	86	43	57	29	71	0	100	14	86	43	57	14	86	43	57	43	57	71	29	71	29
	L	56	44	22	78	56	44	33	67	22	78	22	78	33	67	89	11	22	78	44	56	11	89	44	56
	D	70	30	50	50	50	50	40	60	60	40	0	100	27	73	18	82	36	64	55	45	0	100	73	27
Ger	W	100	0	0	100	60	40	80	20	0	100	80	20	75	25	50	50	0	100	25	75	50	50	75	25
	L	71	29	71	29	29	71	71	29	43	57	29	71	100	0	60	40	80	20	40	60	20	80	80	20
	D	56	44	22	78	67	33	67	33	0	100	56	44	73	27	64	36	45	55	36	64	27	73	64	36
Ne	W	50	50	38	63	25	75	63	38	25	75	88	13	38	63	63	38	50	50	50	50	50	50	50	50
	L	40	60	100	0	20	80	80	20	60	40	80	20	67	33	83	17	33	67	50	50	33	67	67	33
	D	20	80	80	20	100	90	70	30	30	70	70	30	73	27	64	36	45	55	64	36	18	82	36	64

Supplementary Resource 4.4 continued

Team	MS	Dr EA	Pa EA	S EA	Po EA	Dr CA	Pa CA	S CA	Po CA	H SP	L SP	Dir	Poss	Opp Dr EA	Opp Pa EA	S ED	Po ED	Opp Dr CA	Opp Pa CA	S CD	Po CD	Opp H SP	Opp L SP	Opp Dir	Opp Poss
NZ	W	100	0	0	100	100	0	50	50	0	100	100	0	50	50	0	100	50	50	0	100	50	50	0	100
	L	50	50	42	58	25	75	33	67	42	58	92	8	42	58	67	33	25	75	50	50	17	83	42	58
	D	80	20	10	90	40	60	30	70	10	90	100	0	11	89	22	78	22	78	33	67	22	78	22	78
Sp	W	40	60	0	100	20	80	40	60	0	100	40	60	71	29	43	57	29	71	29	71	14	86	43	57
	L	38	63	13	88	38	63	13	88	13	88	75	25	75	25	50	50	50	50	63	38	25	75	88	13
	D	30	70	30	70	30	70	40	60	0	100	30	70	44	56	56	44	44	56	22	78	11	89	78	22

MS = Match Status, Dr = Dribble, Pa = Pass, S = Strong, Po = Poor, H = High, L = Low, Dir = Direct, Poss = Possession, EA = Established Attack, CA = Counter Attack, SP = Set Piece, ED = Established Defence, Opp = Opposition

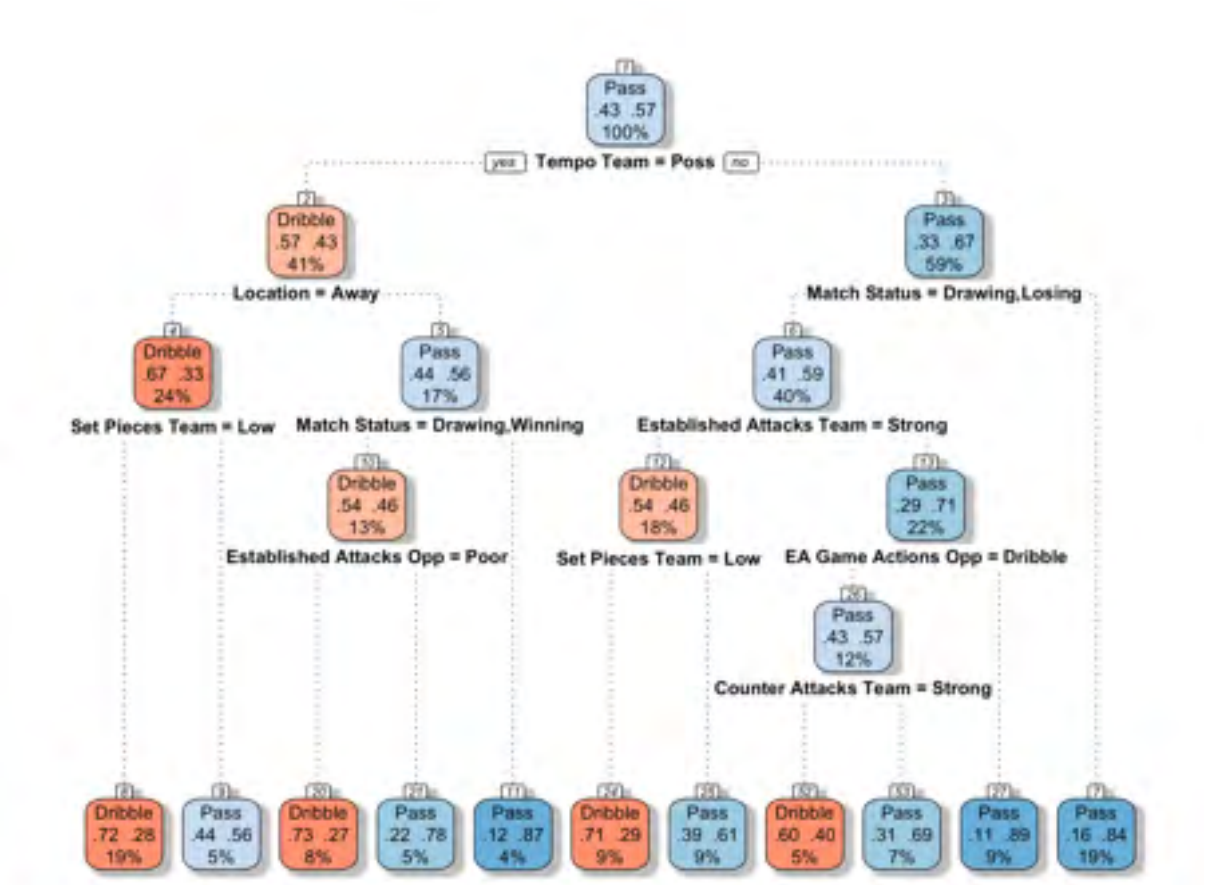
Supplementary Resource 4.5 Game Styles for Women's Teams when winning, losing and drawing. Results are presented as the percentage of games a team was allocated to each game style category from the k-means cluster analysis. Green represents game styles a team implements consistently, red represents a game style that is rarely used.

Team	MS	Dr EA	Pa EA	S EA	Po EA	Dr CA	Pa CA	S CA	Po CA	H SP	L SP	Dir	Poss	Opp Dr EA	Opp Pa EA	S ED	Po ED	Opp Dr CA	Opp Pa CA	S CD	Po CD	Opp H SP	Opp L SP	Opp Dir	Opp Poss
Arg	W	55	45	9	91	91	9	82	18	9	92	64	36	36	64	55	45	27	73	64	36	45	55	73	27
	L	100	0	60	40	60	40	80	20	80	20	40	60	20	80	100	0	60	40	60	40	20	80	60	40
	D	60	40	60	40	87	13	80	20	40	60	40	60	27	73	87	13	47	53	87	13	33	67	67	33
Aus	W	22	78	11	89	22	78	56	44	22	78	78	22	56	44	22	78	78	22	33	67	56	44	33	67
	L	0	100	57	43	43	57	57	43	57	43	71	29	57	43	43	57	71	29	43	57	43	57	71	29
	D	0	100	25	75	25	75	17	83	25	75	67	33	46	54	38	62	46	54	23	77	38	62	38	62
Bel	W	60	40	20	80	60	40	20	80	40	60	80	20	40	60	57	43	60	40	40	60	60	40	60	40
	L	63	38	63	38	63	38	25	75	38	63	100	0	0	100	57	43	29	71	43	57	43	57	0	100
	D	82	18	18	82	64	36	36	64	9	92	45	55	10	90	50	50	30	70	40	60	50	50	30	70
Chi	W	33	67	50	50	17	83	50	50	0	100	33	67	50	50	50	50	33	67	67	33	67	33	67	33
	L	44	56	44	56	11	89	56	44	44	56	11	89	44	56	67	33	56	44	33	67	0	100	56	44
	D	45	55	36	64	45	55	27	73	36	64	64	36	27	73	36	64	55	45	64	36	27	73	45	55
GB	W	80	20	80	20	60	40	80	20	40	60	40	60	67	33	50	50	33	67	50	50	33	67	67	33
	L	57	43	57	43	71	29	57	43	57	43	43	57	43	57	71	29	43	57	57	43	57	43	43	57
	D	27	73	55	45	73	27	36	64	36	64	36	64	73	27	73	27	45	55	73	27	0	100	73	27
Ger	W	83	17	33	67	83	17	33	67	50	50	33	67	33	67	17	83	33	67	50	50	17	83	67	33
	L	91	9	73	27	64	36	45	55	36	64	10	91	45	55	82	18	36	64	73	27	27	73	82	18
	D	100	0	22	78	78	22	22	78	33	67	22	78	56	44	44	56	67	33	44	56	0	100	89	11
	W	21	79	57	43	21	79	50	50	50	50	7	93	57	43	79	21	50	50	86	14	29	71	64	36

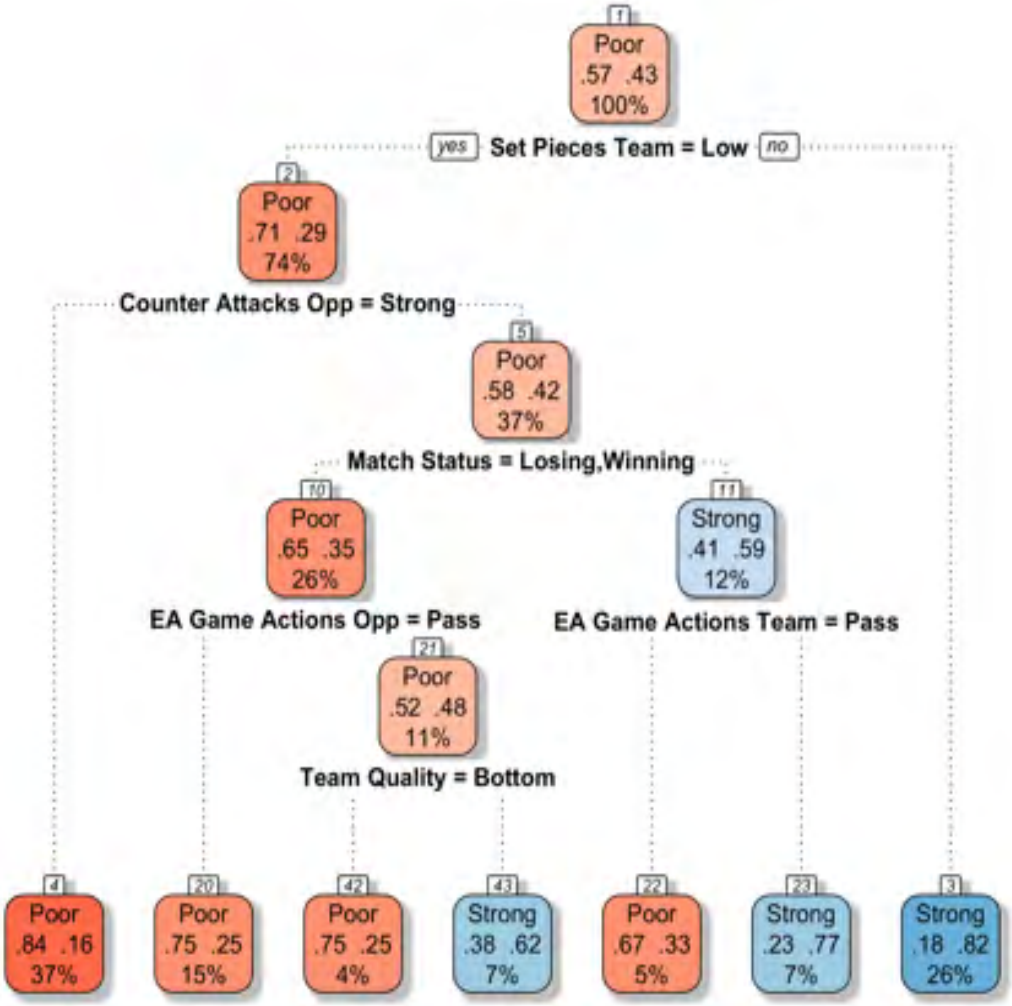
Supplementary Resource 4.5 continued

Team	MS	Dr EA	Pa EA	S EA	Po EA	Dr CA	Pa CA	S CA	Po CA	H SP	L SP	Dir	Poss	Opp Dr EA	Opp Pa EA	S ED	Po ED	Opp Dr CA	Opp Pa CA	S CD	Po CD	Opp H SP	Opp L SP	Opp Dir	Opp Poss
Ne	L	0	100	100	0	50	50	100	0	0	100	0	100	50	50	100	0	50	50	100	0	0	100	100	0
	D	0	100	91	9	27	73	82	18	45	55	18	82	45	55	100	0	55	45	100	0	27	73	82	18
NZ	W	25	75	25	75	25	75	50	50	25	75	75	25	63	38	38	63	50	50	25	75	63	38	50	50
	L	29	71	43	57	14	86	57	43	43	57	100	0	71	29	71	29	57	43	29	71	29	71	57	43
	D	30	70	40	60	0	100	30	70	40	60	80	20	67	33	67	33	67	33	56	44	22	78	44	56
USA	W	33	67	0	100	67	33	0	100	0	100	100	0	33	67	0	100	67	33	0	100	100	0	0	100
	L	33	67	42	58	50	50	17	83	50	50	100	0	42	58	50	50	33	67	33	67	25	75	25	75
	D	42	58	8	92	50	50	17	83	8	92	100	0	38	62	38	62	54	46	46	54	62	38	15	85

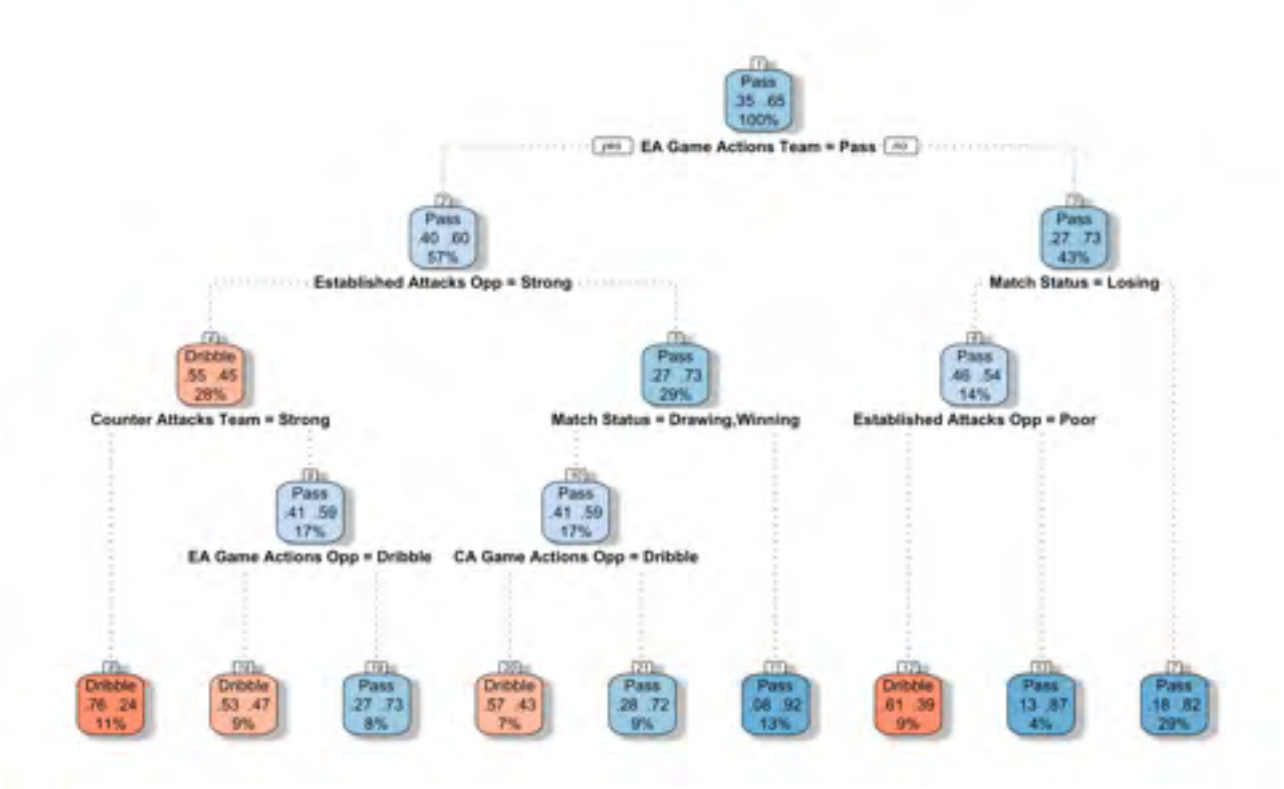
MS = Match Status, Dr = Dribble, Pa = Pass, S = Strong, Po = Poor, H = High, L = Low, Dir = Direct, Poss = Possession, EA = Established Attack, CA = Counter Attack, SP = Set Piece, ED = Established Defence, Opp = Opposition



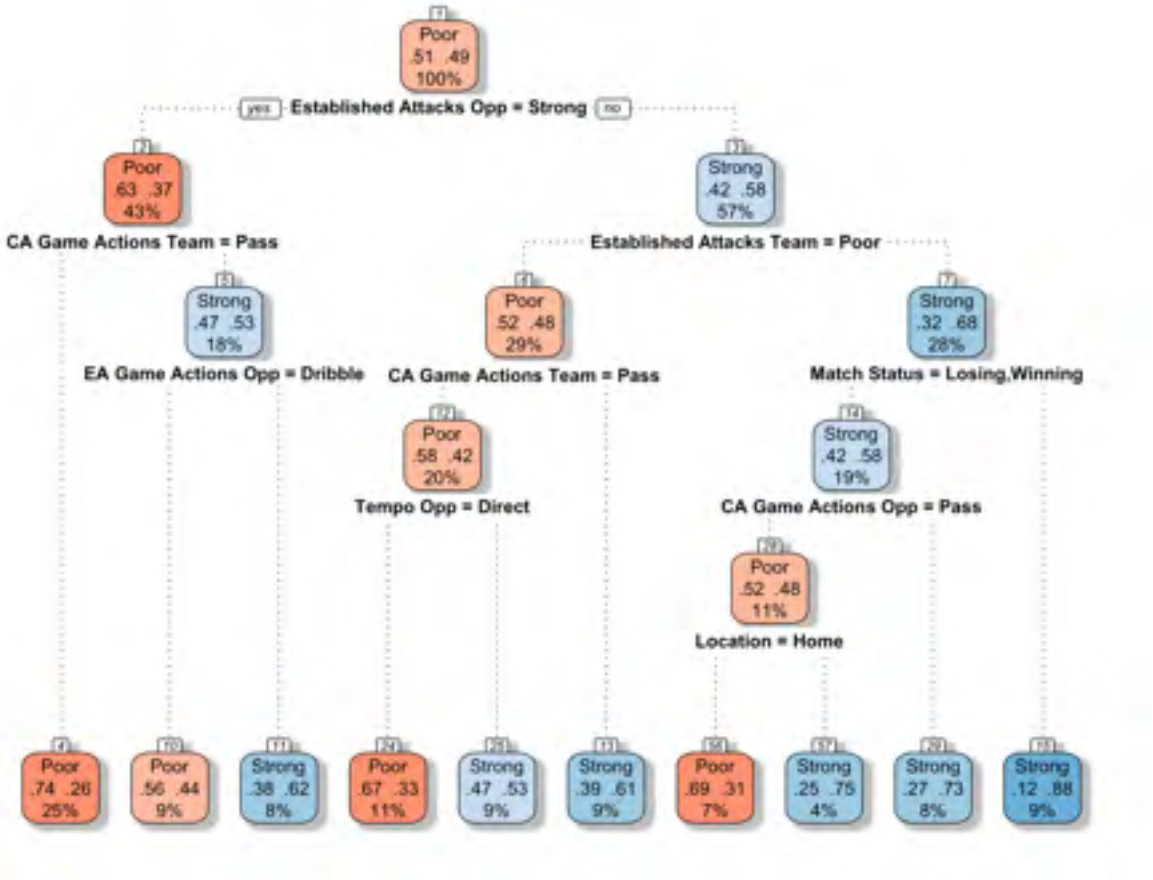
Supplementary Resource 4.6 Decision tree results predicting established attack game actions for men. Red nodes indicate matches are associated with the dribble cluster and blue with the pass cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 72% of matches are likely to be classified as dribbling when a team plays possession, are playing away and has low set pieces.



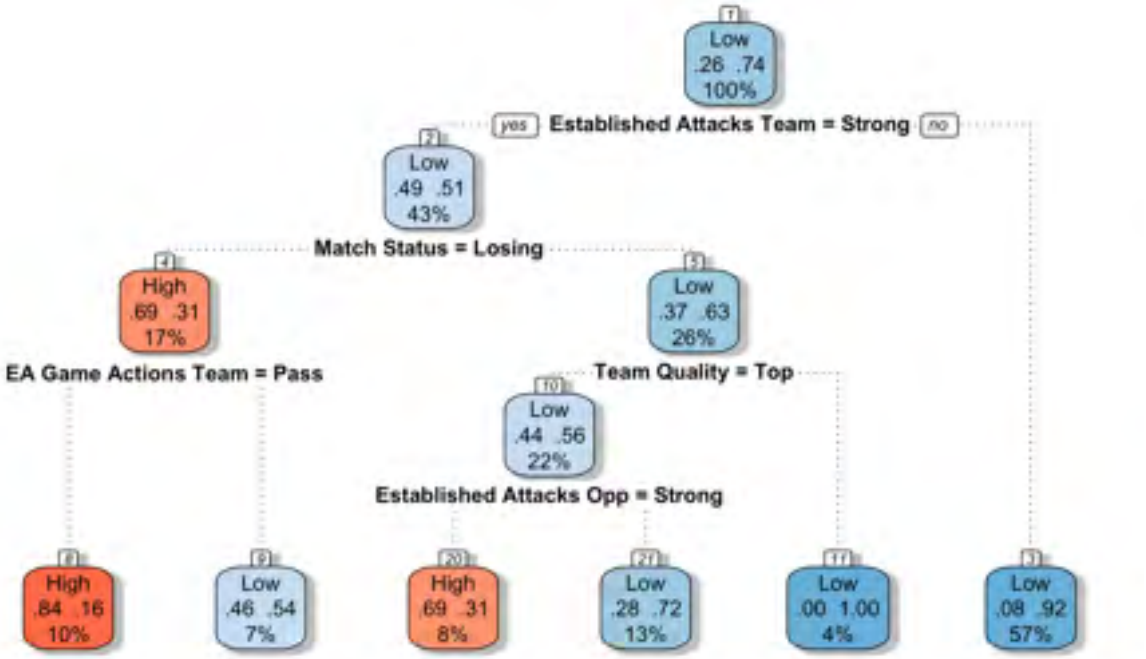
Supplementary Resource 4.7 Decision tree results predicting established attack success for men. Red nodes indicate matches are associated with the poor cluster and blue with the strong cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 84% of matches are likely to be classified as poor when a team has a low number of set pieces and the opposition are strong in counter attacks.



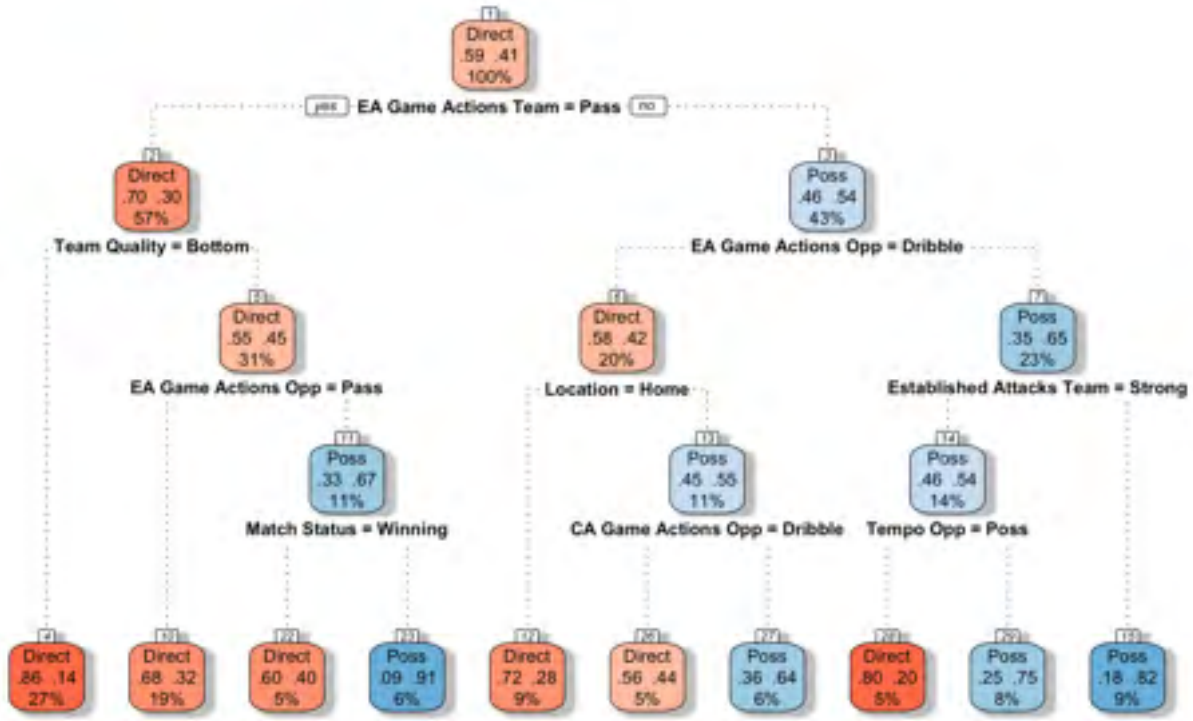
Supplementary Resource 4.8 Decision tree results predicting counter attack game actions for men. Red nodes indicate matches are associated with the dribble cluster and blue with the pass cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 76% of matches are likely to be classified as dribbling when a team uses passes in established attacks, the opposition are strong in established attacks and a team is strong in counter attacks.



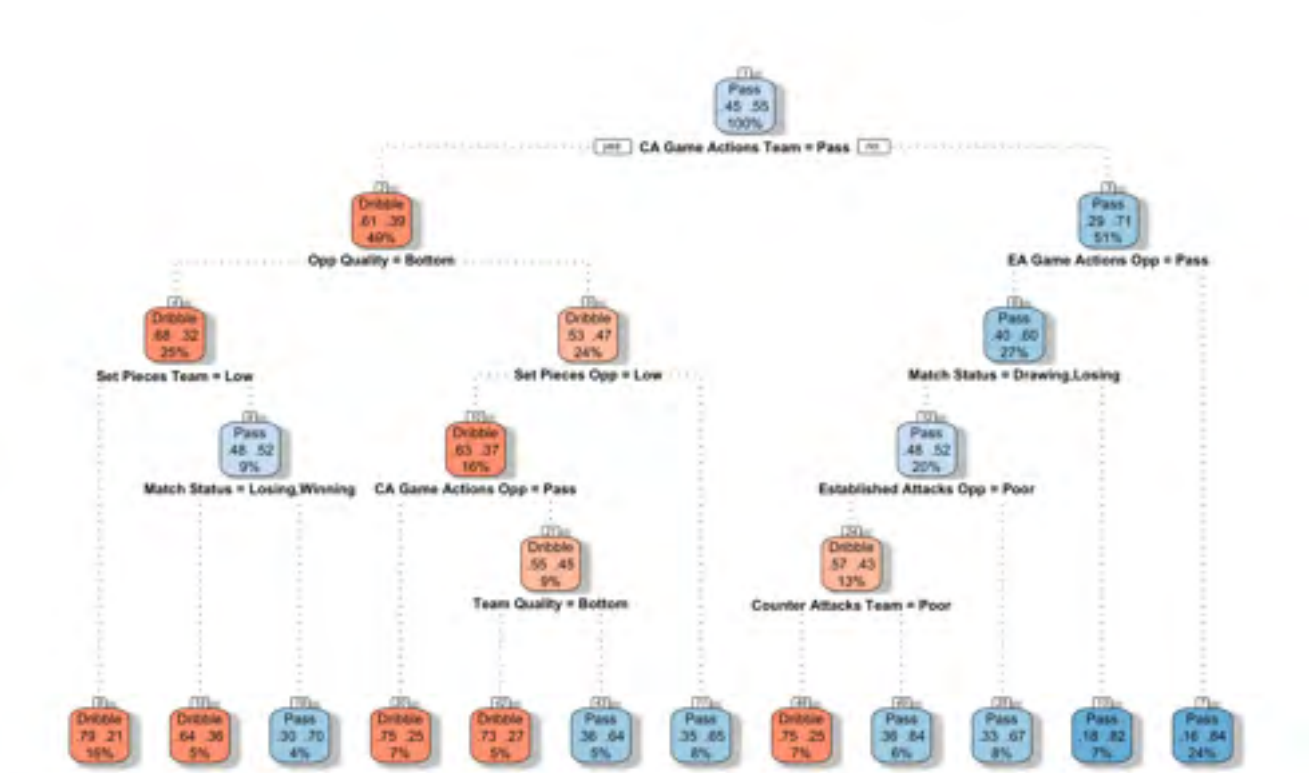
Supplementary Resource 4.9 Decision tree results predicting counter attack success for men. Red nodes indicate matches are associated with the poor cluster and blue with the strong cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 74% of matches are likely to be classified as poor when the opposition is strong in established attacks and a team uses passes in counter attacks.



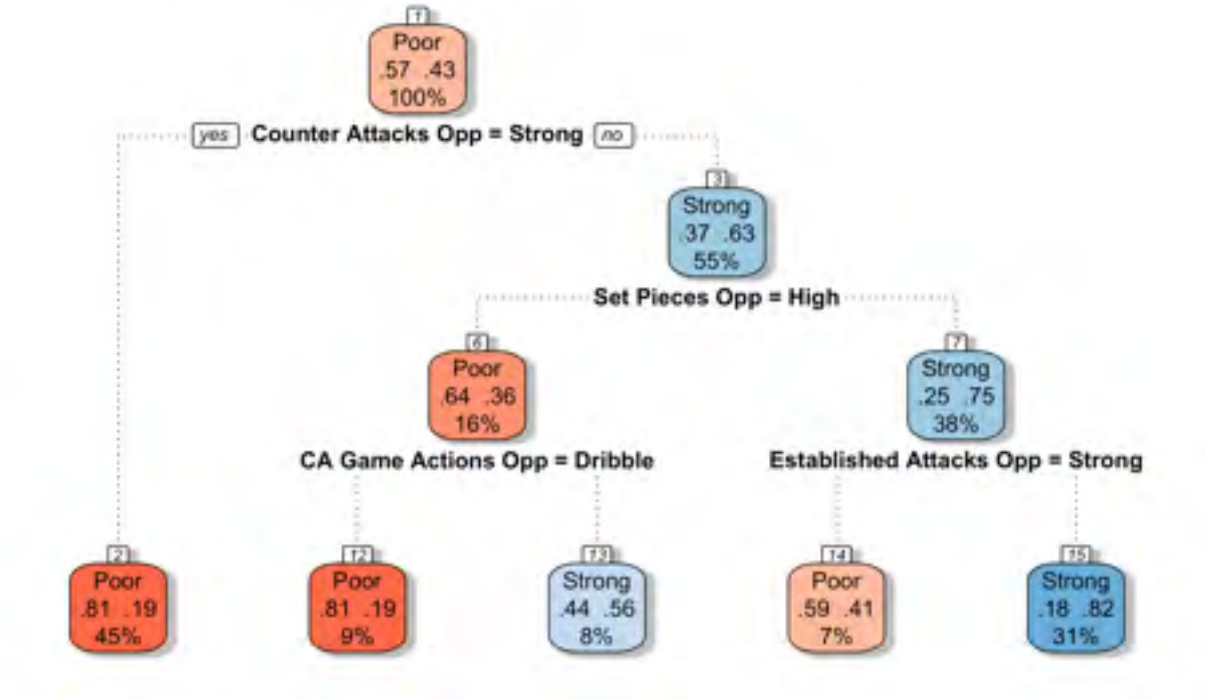
Supplementary Resource 4.10 Decision tree results predicting set piece occurrence for men. Red nodes indicate matches are associated with the high cluster and blue with the low cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 84% of matches are likely to be classified as high when a team is strong in established attacks, and is losing and they use passes in established attacks.



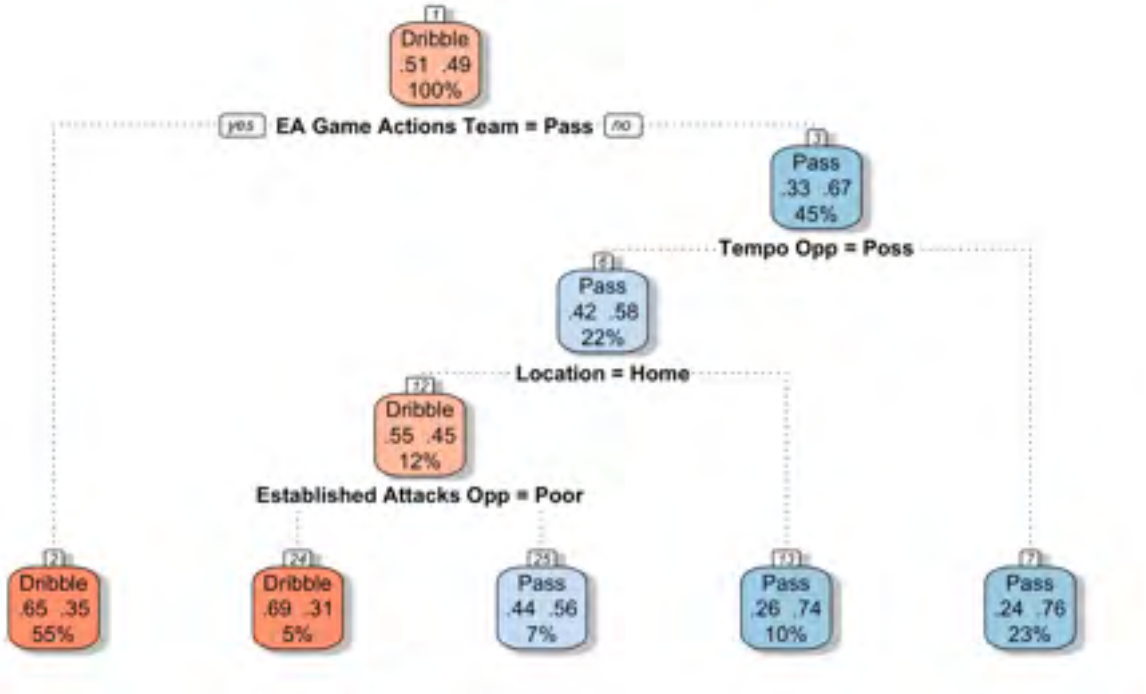
Supplementary Resources 4.11 Decision tree results predicting tempo for men. Red nodes indicate matches are associated with the direct cluster and blue with the possession cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 86% of matches are likely to be classified as direct when a team uses passes in established attacks and are bottom ranked.



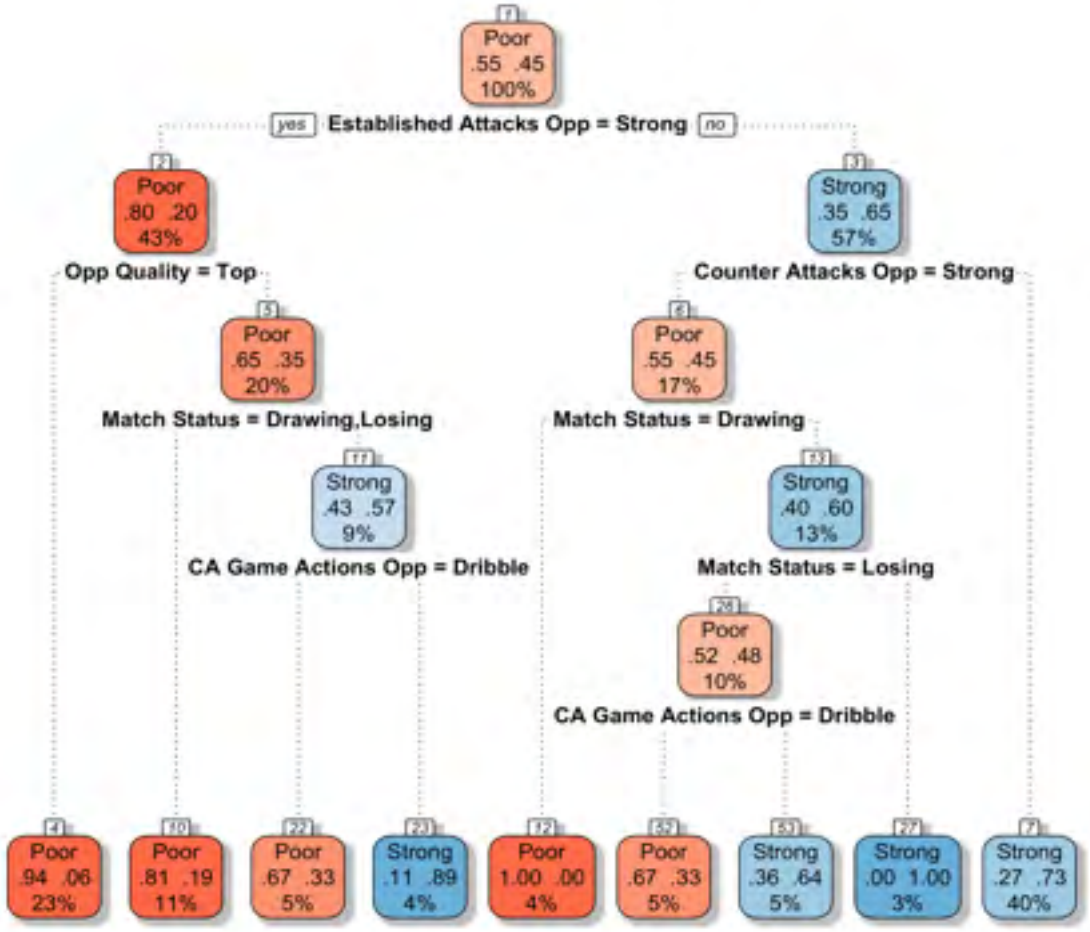
Supplementary Resource 4.12 Decision tree results predicting established attack game actions for women. Red nodes indicate matches are associated with the dribble cluster and blue with the pass cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 79% of matches are likely to be classified as dribbling when a team uses passes in counter attacks, the opposition are a bottom ranked team and a team has low set pieces.



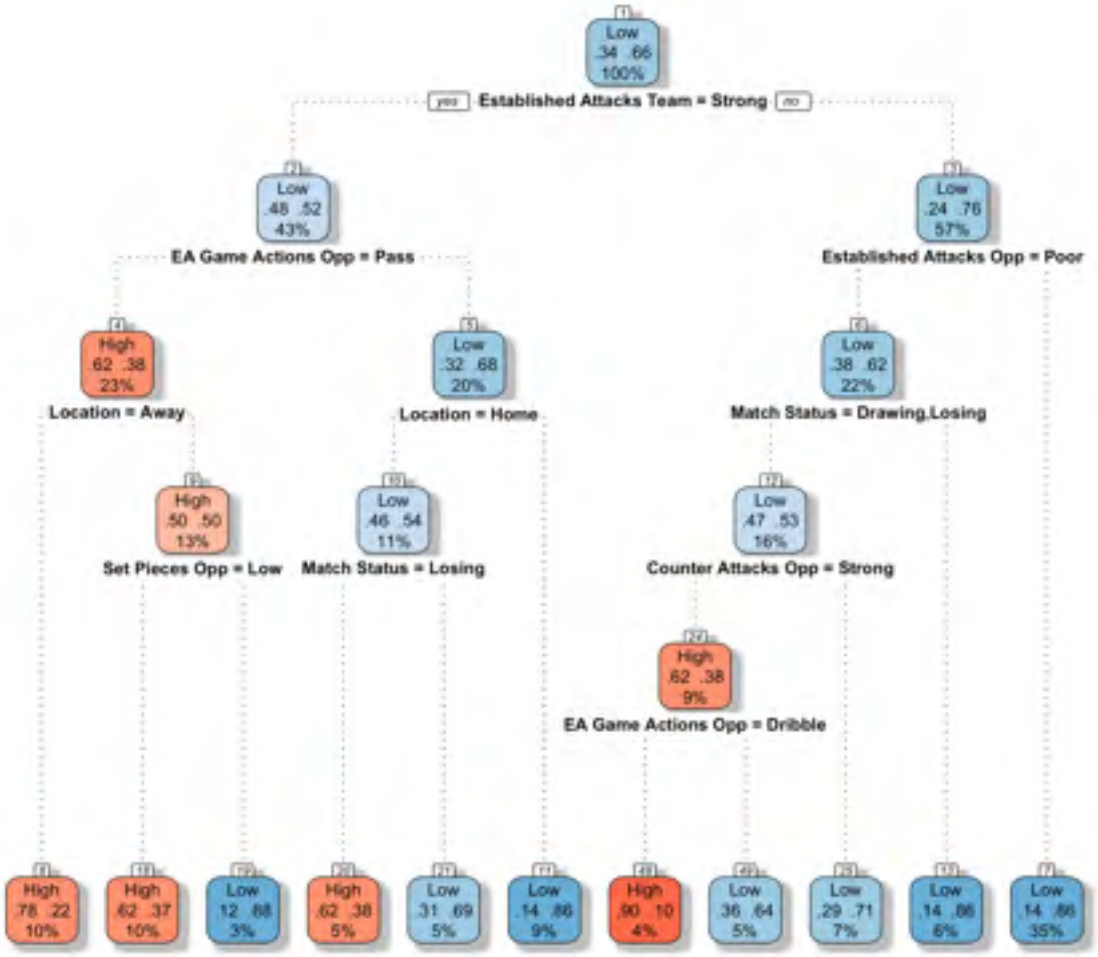
Supplementary Resource 4.13 Decision tree results predicting established attack success for women. Red nodes indicate matches are associated with the poor cluster and blue with the strong cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 81% of matches are likely to be classified as poor when the opposition is strong in counter attacks.



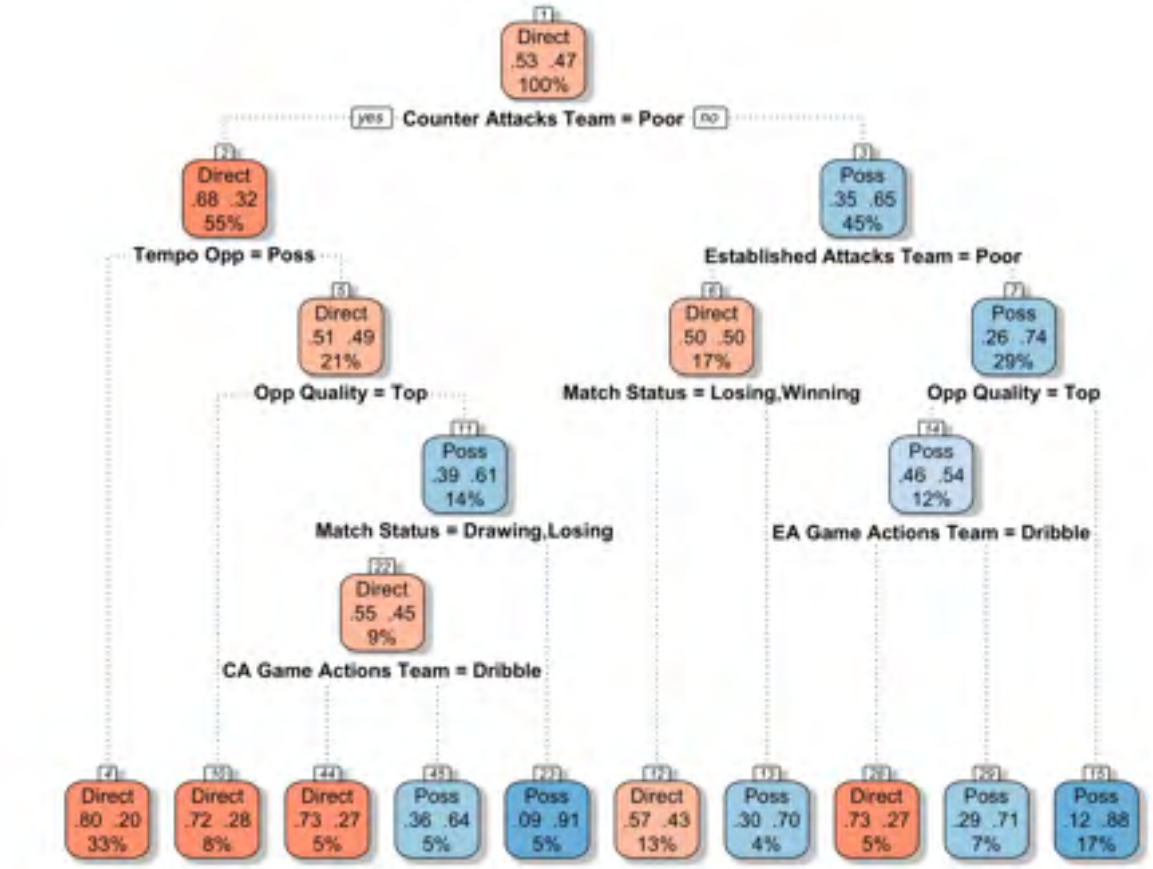
Supplementary Resource 4.14 Decision tree results predicting counter attack game actions for women. Red nodes indicate matches are associated with the dribble cluster and blue with the pass cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 65% of matches are likely to be classified as dribbling when a team uses passes in established attacks.



Supplementary Resource 4.15 Decision tree results predicting counter attack success for women. Red nodes indicate matches are associated with the poor cluster and blue with the strong cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 94% of matches are likely to be classified as poor when the opposition is strong in established attacks and are a top ranked team.



Supplementary Resource 4.16 Decision tree results predicting set piece occurrence for women. Red nodes indicate matches are associated with the high cluster and blue with the low cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 78% of matches are likely to be classified as high when a team is strong at established attacks, the opposition use passes in established attacks and a team is playing away.



Supplementary Resource 4.17 Decision tree results predicting tempo for women. Red nodes indicate matches are associated with the direct cluster and blue with the possession cluster. Team refers to the reference team you are analysing, and opp refers to the opposition. For example, 80% of matches are likely to be classified as direct when a team is poor at counter attacks and the opposition are playing possession.

Declaration of Co-Authorship for Thesis Chapter 5

DECLARATION BY CANDIDATE

In the case of Chapter 5 the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Study design, analysis and interpretation, manuscript preparation	80

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Dr Jocelyn Mara	Design, analysis, editing	No
Prof David Pyne	Design, analysis, editing	No
Dr Marijke Welvaert	Design, analysis, editing	No

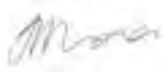
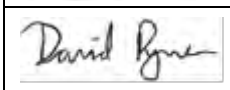
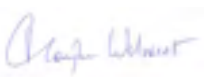
09/08/22

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: Research Institute for Sport and Exercise, University of Canberra

Signatures	Date
	09/08/22
	09/08/22
	09/08/22

Chapter 5 - Predicting the unpredictable: analysing the entropy and spatial distribution of ball movement patterns in field hockey

Lord F, Pyne DB, Welvaert M, Mara JK. (2023) Predicting the unpredictable: analysing the entropy and spatial distribution of ball movement patterns in field hockey. *Biology of Sport* 40: 543-552. https://doi.org/10.5114/biolsport.2023.118018

Abstract

Analysing the ball movement patterns of team invasion sports provides practical insight into successful strategies by identifying how and where to move the ball to create goal scoring opportunities. The aim of this study was to analyse the entropy and spatial distribution of ball movement patterns in international field hockey teams. A notational analysis system was developed in SportsCode™ to analyse 131 matches (n = 57 men, n = 74 women) from the 2019 Pro League tournament. The start and end location of each ball movement and the outcome of each play was recorded. Calculated variables included game possession (%), entropy, possession per zone (%) and progression rates. Decision trees identified that higher circle possession and direct movements to goal from deep attack, and lower build attack and build defence entropy, were the strategies most likely to lead to goal shots. However, teams should be unpredictable when the opposition are organised to maintain possession and unbalance the defence. Match context only had small effects on ball movement strategies highlighting there is more than one way to be successful. Executing strategies that exploit these factors should lead to greater attacking opportunities and success. Analysing the dynamic, complexity of international hockey allows coaches to prepare specific strategies for individual teams.

Key words: performance analysis, strategy, sports analytics

5.1 Introduction

Identifying the ball movement patterns of team invasion sports is a key part of performance analysis. In international women's field hockey, transferring the ball through the wider channels (or edges) of the field and through the side of the circle, before moving the ball to the top of the circle, was identified as the most likely play leading to a goal scoring opportunity [1-2]. The most likely way to score a goal from a penalty corner was via a drag flick from the top of the circle for males, and using a pass to generate a deflection close to goal for females [3]. This type of information is critical for coaches to understand so they may implement and execute effective strategies that increase the chance of team success.

In team invasion sports, there is a delicate balance between being organised and consistent, and being disorganised and creative in ball movement patterns [4]. Unpredictability is linked to success as it creates uncertainty in the defence, whereas consistently utilising the same tactics allows the opposition to prepare counter strategies to impede this movement [4]. For example, higher values of entropy (a measure of unpredictability) were observed in basketball matches with a large deficit win compared to small deficit wins and large deficit losses [5]. This outcome implies that the degree of unpredictability can positively influence a match outcome [5]. Identifying ball movement patterns and the consistency or unpredictability of these patterns, provides insight into a team's game style and their adaptability to match context. Associating the tempo and control of a team with the areas they typically play in provides critical information for developing strategies, styles and tactics. A coach can use these insights to determine which areas of the field their team needs to control, and the type of defensive structure to implement based on the consistent or unpredictable nature of the opposition.

Research investigating movement patterns in team invasion sports has increased in recent years given improvements in technology. Player and ball tracking can occur in real time using semi-automated vision-based tracking systems, or a local (LPS) and global positioning system (GPS). Team formation may influence the spatial distribution of possession across the field and as such, tracking player movement alongside ball movement can provide a comprehensive insight into how a team changes formation as the ball moves. However, tracking technology can be expensive, and access to one team's GPS data only provides "half the story". Therefore, these techniques are largely restricted to professional teams. Alternatively, Stockl and Morgan [2] tracked the ball movements of hockey teams manually to identify the most likely pattern leading to a goal scoring opportunity. However, they only

focused on the spatial distribution of possession, and consequently two teams may have similar profiles, but achieve different outcomes. Analysing spatial distribution alone does not provide insight into how a team moved across the field, how quickly they progressed the ball, nor how predictable they were in their movements. The combination of these variables provides a holistic perspective of strategy, and can differentiate the attacking abilities of teams. It also provides an indication of how a team is structured and moves across the field without tracking player movement by identifying the key areas of possession and the locations that are connected.

There is an opportunity to develop new methods of analysing ball movement patterns with the resources available in field hockey that provides practical insight into performance. The primary aim of this study was to analyse the entropy and spatial distribution of ball movement patterns of international hockey teams. The secondary aims were to assess the influence of match context on these movement patterns, and identify the most common attacking movement patterns related to play outcomes.

5.2 Methods

Video footage of matches from the 2019 International Hockey Federation (Fédération Internationale de Hockey, FIH) Pro League (n = 57 men, n = 74 women) were accessed and analysed for this study. Hockey Australia provided access to the data base of video footage captured from each match during the tournament. The majority of games included video footage captured from each respective team's analyst from behind the goals which provides a greater view of the field. This output was synced with video footage from TV coverage of the game filmed from a side on angle that is zoomed in on the player with the ball. The tournament was an invitational competition played in a home and away season by 8 (men) and 9 (women) teams ranked in the top 12 FIH teams. Teams included Argentina, Australia, Belgium, China (women only), Great Britain, Germany, Netherlands, New Zealand, Spain (men only) and United States of America (women only). Ethical approval was granted by the University of Canberra Human Research Ethics Committee.

Computerised performance analysis software, SportsCode™ (Version 11, Hudl, https://www.hudl.com), was used to retrospectively analyse the match video footage. Variables related to the team in possession, ball movement in general play (i.e. not set pieces), the outcome of the play, and the match context, were annotated using a specifically designed code window (Figure 5.1). To track ball movement, the field was divided into 5 x 8

cells (i.e. 40 field zones in total). Each cell on the field that a player had control of the ball was annotated. If a player dribbled the ball through multiple cells each individual cell the ball was controlled through was notated. However, when passing, only the cells where the ball was passed from, and received, were notated.

The outcome was also recorded at the end of the possession and included a goal shot, penalty corner, restart (long corner or ball played from within the circle to outside the circle and possession retained), or turnover. Only the initial outcome was recorded; for example, if a goal shot resulted in a turnover only a goal shot was recorded, to ensure the pattern of play was analysed rather than execution of the goal shot. If a goal shot from general play or a penalty corner resulted in a rebound for the attacking team, a ball movement would not be recorded to limit movement patterns to the creation of goal scoring opportunities. A new movement pattern was only initiated if a team retained possession after a goal shot or penalty corner once the ball had left the attacking circle.

Contextual variables were recorded for each game including match status at the time of possession (winning, losing or drawing) and team ranking at the end of the tournament (1^{st} - 8^{th}/9^{th}). Relative team quality was calculated retrospectively by subtracting the reference team rank from the opposition team rank. For example, a relative team quality of +7 or -3 indicated a team was ranked 7 places higher and 3 places lower than the opposition.

A pilot study was completed on a randomly selected game from the database to ensure all necessary variables were recorded and the size of the cells in the code window were appropriate. Intra- and inter-coder reliability tests were also conducted on one random game to ensure coding was completed consistently and accurately. The intra- and inter-coder Kappa values were calculated as 0.92 and 0.91 for start locations, 0.91 and 0.87 for end locations and 1.0 and 1.0 for outcomes, respectively. These values indicate “very good” levels of agreement between observers [6] and the notational analysis process was deemed reliable.

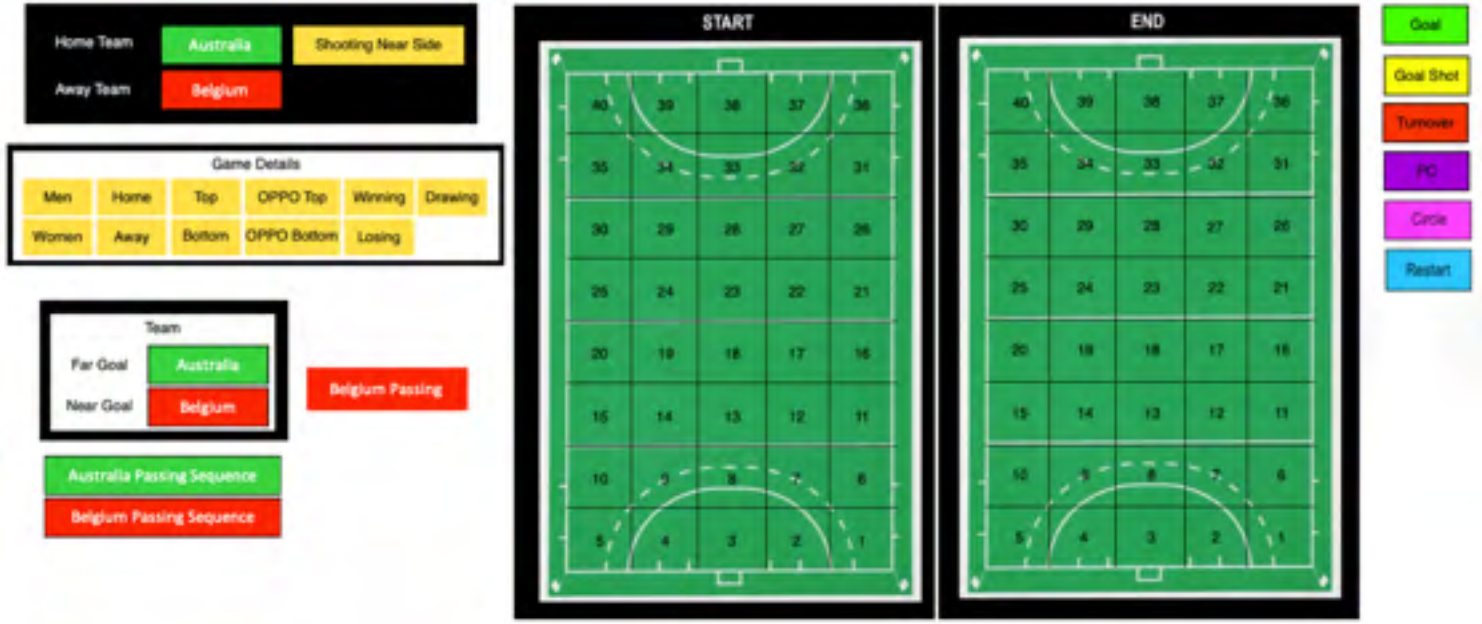


Figure 5.1 Notational analysis system used to capture ball movement patterns in SportsCode showing an example game between Australia and Belgium. An analyst would choose the team in possession, the start and end location of each ball movement followed by the outcome at the end of a play. The field orientation would switch direction depending on which team was in possession so cell 1 always corresponded to the attacking 25 left corner and cell 40 to the defensive 25 right corner of the field.

5.3 Data Analysis

The XML file for each game, which contained all variables recorded in chronological order, was exported from SportsCode™ (Version 11, Hudl, https://www.hudl.com) and imported into Microsoft Excel™. Results were then imported into RStudio 1.3.1093 (RStudio Inc, https://www.rstudio.com) for subsequent data analysis using R (version 4.03) [7]. Each team per match per match status (winning, losing or drawing) was analysed individually to identify how and where they moved the ball under different match situations. The 40 cells were grouped into 7 attacking zones based on the different phases of attack occurring in each zone. Table 5.1 describes the definitions for each attacking zone and their respective phases of attack, and Figure 5.2 illustrates these zones on the field.

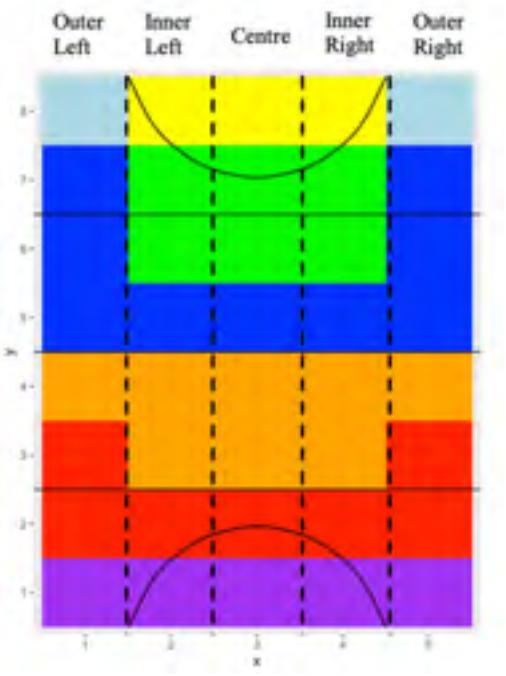


Figure 5.2 Field hockey pitch divided into seven attacking zones; yellow = circle, light blue = corners, green = deep attack, dark blue = build attack, orange = build defence, red = outlet, purple = deep defence.

Table 5.1 Attacking zone definitions relating areas on the field to phase of attack

Attacking Zone	Location	Aim	Players and ball movement
Circle	Areas closest goal encompassing the majority of the circle	Create goal scoring opportunities	Attackers attempt to move the ball along the baseline to the centre of circle as this is the best goal scoring position given the angle and proximity to goal.
Corners	Two corners of the attacking 25 bordered by the baseline and sideline	Create circle entry	Safer path into the circle as the offence look to move the ball around the edge of the opposition defence along the baseline into the circle. However, the longer route into the circle provides greater opportunities for the opposition to get numbers to better goal scoring positions.
Deep Attack	Centre of the attacking half and top of the circle	Create circle entry and/or goal scoring opportunity	Attackers attempt to move directly to the top of the circle for a goal shot or pass closer to goal, providing the more direct route to goal and best angle for a goal shot. However, it is also a riskier option as a team must play through the opposition defenders clustered around the circle, increasing the chances of a turnover and opposition counter attack.
Build Attack	Edges of the attacking half and across the attacking side of the half way line	Manipulate defence to create space for an attacking opportunity	Attack look to manipulate the opposition defence by passing back and around the midfield. Opposition condense into their defensive half, protecting the direct routes to goal. The depth and width of this shape reflects the spread of the attackers in an attempt to maintain possession by transferring the ball backwards or across the field.
Build Defence	Defensive side of the half way line and centre of the defensive 50	Gain ground, manipulate defence	Until ground can be gained defenders transfer the ball from side to side to attempt to generate holes in the opposition's structure. Generally, a team will have one or two central defenders and two wide defenders reflecting the shape of this zone.
Outlet	Areas used to take free hits from the defensive 25 and the likely path out from defence	Gain ground	Opposition are set up in front of the ball, protecting the centre but allowing the player to move the ball to the sideline. Attackers generally have two central defenders and two higher wider defenders for moving the ball up the sideline.
Deep Defence	Area along the baseline of the defensive 25	Protect goal	Danger zone for attacking team, turnover in this area could lead to a goal shot or restart of play for the opposition. Attackers look to move wide towards the space near the sideline to remove ball from circle and away from the opposition.

Data were analysed for entropy and spatial distribution which included game possession, possession per zone, and progression rates (i.e. the percentage of ball movements in different directions). Each variable was calculated per match status, then each individual team's data was further divided by relative team quality and play outcomes and variables recalculated. Time in possession was calculated by summing the total time of all actions completed per cell location by calculating the difference between start and end times for each movement. The percentage of game possession for a team in a single match was calculated by dividing the total time for the reference team's game actions by the total time for both team's game actions per match. This metric reflected how much control a team had per match. Possession per zone (%) was calculated by dividing the time for all game actions in one attacking zone by the total time in possession for all attacking zones for a team. This metric indicated the offensive opportunities of a team.

Shannon's entropy (H) was calculated to determine the unpredictability of ball movement for each cell location [5], which reflects the passing range of a team and the variety of ways they may attack. The equation for Shannon's entropy is shown in Equation 5.1 where p_i is the probability of the ball entering a certain location, and n is the total number of locations the ball can enter [8].

$$\text{Equation 5.1: } H(X) = H(p_{1,}, \dots, p_n) = -\sum_{i=1}^{n} p_i \log_e p_i$$

For example, a team has 30 ball movements starting from cell 10. Of the 30 ball movements 5 end in cell 9 (P = 0.17), 7 end in cell 10 (P = 0.23), 8 end in cell 14 (P = 0.27), 4 end in cell 15 (P = 0.13), and 6 end in cell 20 (P = 0.20).

$$H(\text{Start Cell 10}) = p(9) \times \log_e\left(\frac{1}{p(9)}\right) + p(10) \times \log_e\left(\frac{1}{p(10)}\right) + p(14) \times \log_e\left(\frac{1}{p(14)}\right) + p(15) \times \log_e\left(\frac{1}{p(15)}\right) + p(20) \times \log_e\left(\frac{1}{p(20)}\right)$$

$$H(\text{Start Cell 10}) = 0.17 \times \log_e\left(\frac{1}{0.17}\right) + 0.23 \times \log_e\left(\frac{1}{0.23}\right) + 0.27 \times \log_e\left(\frac{1}{0.27}\right) + 0.13 \times \log_e\left(\frac{1}{0.13}\right) + 0.20 \times \log_e\left(\frac{1}{0.20}\right)$$

$$H(\text{Start Cell 10}) = 1.58$$

The minimum entropy value of 0 indicates a highly predictable movement pattern and reflects ball movements that occur 100% of the time. The maximum entropy value is determined by taking the natural logarithm of the number of locations included in the calculation. If the ball is transferred from one cell to every other location on the field, then *n* is equal to 40. This outcome reflects that there is an equal probability that a ball movement could move to any cell on the field. The maximum entropy that can be observed is 3.69. The mean was then calculated for each attacking zone. Entropy values were normalised by dividing by the maximum entropy, so a minimum value is 0 and maximum is 1.

Progression rates were calculated to determine the intent of teams to attack directly and progress the ball towards goal, or maintain possession. A novel method was developed to assess progression rates. Progression rates were calculated for each of the 40 cells by observing the frequency of ball movements that ended in each cell and converting to a percentage. Cells were then grouped into the 7 attacking zones, for start and end locations, and averages calculated for each zone. Movements were simplified to four direction categories so they could be compared between zones. Direction categories included:

- Back: ball movement was received in a zone behind the starting zone
- Stay: ball movement started and ended within the same zone
- Forward: ball movement was received in the adjacent zone in front of the starting zone
- Goal: ball movement ended in a zone 2 or 3 ahead from a starting zone in the defensive half, or ended in a zone more direct to goal through the centre of the field from the attacking half

Table 5.2 shows the description of categories for each attacking zone. Attacking team profiles were developed by analysing when a team was in attack, and defensive team profiles by calculating opposition values for each team.

Table 5.2 Movement progression categories for each attacking zone representing the least to most direct attacking options to take from left to right. For example, a team that has possession in the Circle (first row below), if they move into the Corners or Build Attack zones it is considered a movement back, if they dribble or pass within the circle the team has not changed zones so it is considered as a stay movement, and if the team moves the ball to the Deep Attack zone it is considered to be movement in the forward direction as the ball remains in an attacking position for a goal shot, even though the initial ball movement is away from goal. NA = not applicable

Directness	**Least**	→	→	**Most**
Start Zone	**Back**	**Stay**	**Forward**	**Goal**
Circle	Corners Build Attack	Circle	Deep Attack	NA
Corners	Build Attack Build Defence	Corners	Deep Attack	Circle
Deep Attack	Build Attack Build Defence	Deep Attack	Corners	Circle
Build Attack	Build Defence Outlet	Build Attack	Corners	Deep Attack Circle
Build Defence	Outlet Deep Defence	Build Defence	Build Attack Corners	Deep Attack Circle
Outlet	Deep Defence	Outlet	Build Defence	Build Attack Deep Attack
Deep Defence	NA	Deep Defence	Outlet	Build Defence Build Attack

5.4 Statistical Analysis

Statistical analysis was completed in RStudio separately on male and female data. Data were transformed to a z-score to ensure equal weighting in the analysis. Linear mixed models, using the '*lmer*' function from the *'lme4'* R package [9], were used to analyse the effect of contextual variables and attacking zones on game possession, entropy, possession per zone and progression rates. In the first model, match status and attacking zones were identified as fixed factors, and team and game number included as nested random factors, and relative team quality as a random factor. In the second model, relative team quality and attacking zones were identified as fixed factors and team, game number and match status included as nested random variables. The interaction between fixed factors was analysed in both models. Assumptions of normality and homoscedasticity were checked via visual inspection of residual plots and histograms.

Likelihood ratio tests, using the *'anova'* function, were used to determine the statistical significance of a fixed or random factor by comparing models with and without the variable in question. To identify significant pairwise comparisons in a model assessing match status, the '*emmeans*' function with false discovery rate correction [10] from the '*emmeans'* R package [11] was employed. To assess relative team quality, the *'emtrends'* function from the '*emmeans'* R package [11] was used. Results are presented as unstandardised estimated marginal mean ± 95% confidence limits (CL) and considered significant when $p < 0.05$. Practical differences were identified by considering the aim of the attacking zone, and the minimal difference in possession, entropy or progression rates needed to achieve this aim.

Decision trees were developed, using the '*rpart*' function from the '*rpart'* R package [12], to assess the variables determining the outcome of a play - goal shot, positive (penalty corner or restart), or turnover. Forty predictor variables were included in the model including entropy, possession, and movements back, stay, forward and goal for each attacking zone. The prediction accuracy of the model was assessed by splitting the data into train (70%) and test (30%) data sets and using the *'predict'* function from the *'caret'* R package [13]. The overall accuracy was 86% for men and 91% for women with sensitivity (true positives) >79% and specificity (true negatives) >88%. The decision tree model was deemed able to accurately distinguish play outcomes. The *'varImp'* function from the *'caret'* R package [13] was used to identify which variables distinguished play outcomes.

5.5 Results

5.5.1 Match Status

Men's and women's profiles when winning, losing and drawing and pairwise comparisons from linear mixed models are presented in Figure 5.3. For both men and women, practical differences were observed between teams for game possession and possession per zone. For men, losing teams had greater game possession (8.1 ± 1.7%; mean ± 95% CL) and greater possession (3.3 ± 3.0%) in deep attack than winning teams. Winning teams had greater possession (5.9 ± 5.2%) in outlet than losing teams. For women, losing teams had greater game possession (6.1 ± 1.1%) and greater possession in build attack (5.0 ± 4.5%) than winning teams. Winning teams had greater possession in deep defence (4.1 ± 3.9%) and outlet (7.3 ± 6.0%) than losing teams.

Figure 5.3 A comparison of ball movement patterns when winning, losing and drawing for men's (left) and women's (right) teams in the 2019 Pro League tournament. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. For example, for winning male teams that held possession in deep defence, 46% of ball movements stayed within deep defence and 49% went forward. Z-score indicates above (green) and below (red) average performance compared to the league average. D = significant difference compared to drawing, L = significant difference compared to losing, and W = significant difference compared to winning teams. For example, game possession for men, losing teams have greater possession than drawing and winning teams and drawing teams have greater game possession than winning teams.

5.5.2 Team Quality

Men's and women's profiles are shown for lower-, similar- and higher-ranked teams (relative to the reference team) and trends identified from linear mixed models in Figure 5.4. For men, game possession increased by 1.4 % (± 0.6%) with an increase in team quality by one ranking (place). Entropy increased by 0.0057 (± 0.0053) in deep attack and by 0.0062 (± 0.005) in build attack with an increase in ranking. Possession increased by 0.4% (± 0.3%) in build attack, and decreased by 0.8% (± 0.3%) in outlet with an increase in ranking by one.

For women, practical differences were observed in game possession, an increase of 0.9% (± 0.4%) was seen with an increase in one ranking (place). As ranking increased, entropy in deep attack increased by 0.0065 (± 0.0041). Ball movements that stayed in the corners were higher for lower ranked teams. Movements directed towards goal were higher for relatively higher ranked teams from corners and deep attack.

5.5.3 Play Outcomes

Men's and women's profiles when a play ends in a goal shot, positive outcome, or a turnover, and the variables important in distinguishing play outcomes, based on decision tree models, are shown in Figure 5.5. A total of 16 variables were considered important for men, with the three highest-ranked variables including Circle Possession, Build Defence Entropy and Build Attack Entropy. For women, a total of 13 variables were considered important, and the three most important variables were Deep Attack Goal, Build Defence Entropy and Build Attack Entropy.

5.5.4 Team Profiles

Attacking and defensive team profiles are illustrated in Supplementary Resources 5.1 - 5.8 for men and 5.9 - 5.17 for women when winning, losing and drawing. An example profile for Netherlands women is displayed in Figure 5.6 for attacking and defensive variables.

Figure 5.4 A comparison of ball movement patterns when relative team quality is +7, +1 and -7 for men's (left) and +8, +1 and -8 for women's (right) teams in the 2019 Pro League tournament. Results are presented as average of ball movement variable on the x axis per relative team quality per attacking zone on the y axis. For example, for male teams that held possession in deep defence and were ranked 7 places higher than the opposition, 47% of ball movements stayed within deep defence and 47% went forward. Z-score indicates above (green) and below (red) average performance compared to the league average. * indicates significant trend in relative quality of teams. For example, game possession for men decreases with ranking from teams ranked 7 places higher than their opposition to teams ranked 7 places lower.

Figure 5.5 A comparison of plays ending in a goal shot, positive or turnover for men's (left) and women's (right) teams in the 2019 Pro League tournament. Results are presented as average of ball movement variable on the x axis per play outcome per attacking zone on the y axis. For example, for male teams that held possession in deep defence and the play ended in a goal shot, 31% of ball movements stayed within deep defence and 58% went forward. Z-score indicates above (green) and below (red) average performance compared to the league average. Superscripted numbers indicate variables important in distinguishing play outcomes in order of importance. For example, circle possession was the most important variable for men, with plays ending in a goal shot having greater circle possession than positive outcomes and positive outcomes having greater circle possession than turnovers.

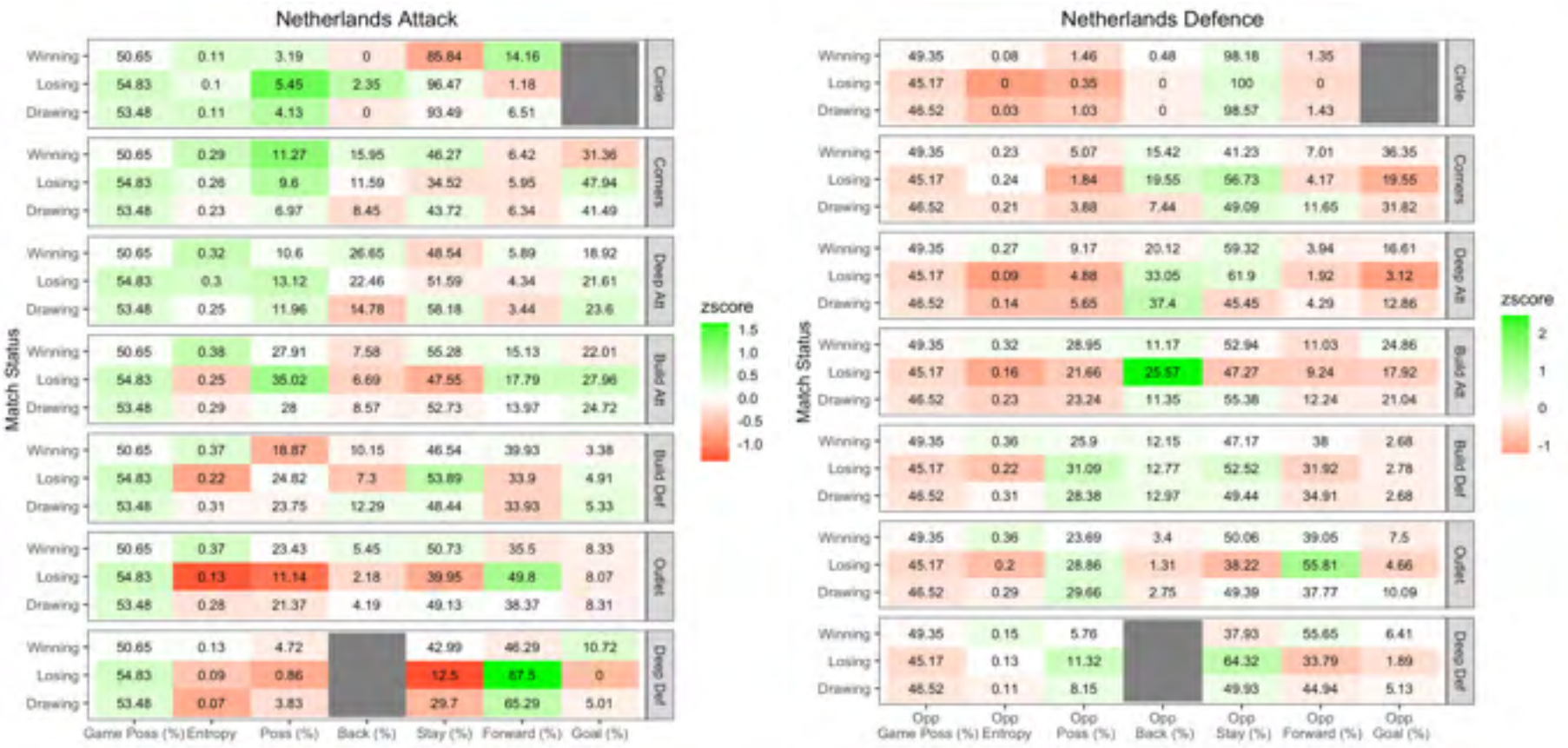


Figure 5.6 Attacking (left) and defensive (right) ball movement variables for Netherlands women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

5.6 Discussion

This study analysed the entropy and spatial distribution of ball movement patterns in international field hockey. Possession has been a well-analysed metric in team invasion sports [2,14], and entropy is an emerging concept [5, 15]. However, progression rates have not yet been analysed nor the combination of these variables. Hockey is a dynamic, complex system with multiple factors influencing ball movement patterns [16]. Therefore, more detailed and practical insights into performance are gained by analysing the relationship between these variables. The results of this study highlight the importance of analysing the multitude of factors influencing strategy so that coaches have the level of detail needed to develop specific strategies for success in different match situations.

Differences in ball movement variables were evident between play outcomes in the FIH Pro League, and similar trends were observed between genders highlighting several basic principles of hockey. A turnover was likely to occur when a play had greater entropy, higher possession in the defensive half, and a greater proportion of actions staying in defence or moving back in attacking positions. In contrast, a positive outcome resulted from plays with lower entropy, but higher possession in corner zones as teams had a greater proportion of actions moving forward. Goal shots, also resulted from plays with lower entropy, but higher possession in deep attack and the circle, and a greater proportion of actions moving more directly to goal. The ability to progress the ball quickly and more directly through the centre of the field provides greater opportunities for goal shots before the opposition can organise their defence. An inability to penetrate the defence and progress directly to goal allows greater time for the defence to protect the direct lines to goal, subsequently more likely resulting in a turnover when a team is held up in the defensive half and a positive outcome in attacking positions. This outcome reflects earlier research indicating a goal scoring opportunity was more likely if the ball was possessed near, or at the top of the circle [2], and a goal scored the further up the pitch the ball was regained [1]. Understanding differences between these play outcomes, assists both the analyst and coach interpret team profiles and assess the attacking ability of a team.

Hockey is a low scoring game and our results show >75% of game possession were related to plays ending in a turnover. Thus, goal scoring opportunities are likely to result from a sequence of plays that aim to disorganise the defence by building pressure in attacking positions, while restricting the opposition doing the same. For both men and women, teams ranked relatively higher had greater game possession, and entropy and possession in zones in

the attacking half. Although these effects were small, they reflect the trend for greater differences in attacking opportunities as the relative team difference increased given the ability of higher ranked teams to control the ball in the attacking half. As all teams were ranked within the top 12 international teams in 2019, a larger effect may have been seen if there were teams competing from a greater range in rankings. Nonetheless, this outcome is consistent with analysis in soccer where the top-ranked teams completed greater actions related to ball possession and ending actions [17], had the greatest mean values of entropy [15], and greater width and length in attack against weaker opposition [18]. This pattern of play makes higher ranked teams more unpredictable and harder to defend against as the opposition has to protect a larger portion of the field. Consequently, higher ranked teams are more likely to create greater attacking opportunities per game.

When analysing the effect of match status on ball movement variables for both men and women, compared to teams that are drawing, losing teams have more game possession, greater entropy and possession in the attacking half. While winning teams have less game possession, but greater entropy and possession in the defensive half as they are more likely to move backwards. Although these effects may be small, they reflect a tendency for teams to change strategy when there is a change in match status. A larger effect may be observed if score differences and interaction with relative team quality are assessed. Nonetheless, winning teams are more likely to retreat to their defensive half to protect their goal, while losing teams are likely to increase their defensive pressure higher up the ground. This pattern is observed in soccer, with losing teams having greater possession in the attacking half, and more likely to increase their use of build-up and sustained threats plays which increased a team's level of game possession, and winning teams having greater possession in the defensive half, and increased use of direct attacks [14, 19]. The relationship between entropy and possession reflects the change in strategy with match status that increases the attacking opportunities of losing teams, while reducing those of winning teams.

It appears there are two key factors related to success which a coach can use to develop effective strategies. First, it is the ability of a team to get the ball to the build attack zone quickly, and secondly maintaining possession in the attacking half using a variety of movement patterns, that increases the chance of the play being successful. We have showed that successful hockey teams and plays revolve around possession in the attacking half, utilising the length and width of the attacking half to disorganise the defence and create space to attack the direct routes to goal. This is reflected in research identifying soccer teams were

more likely to create a goal scoring opportunity from a counter attack or regaining the ball in the attacking third [20]. In basketball only front (attacking) court entropy, as opposed to full court entropy was related to success [5], and entropy was positively correlated to generating future high probability shots [21]. Therefore, teams may be predictable when the opposition is disorganised, and immediate scoring opportunities present themselves, but unpredictable when the opposition are organised to maintain possession while attempting to unbalance the defence.

The relatively small effect of match status and team quality on ball movement patterns may reflect the different strategies individual teams use in different situations to be successful. For example, Netherlands (women) are a dominant team as they have high game possession, and entropy and possession in the attacking half while limiting their oppositions attacking possession by forcing them backwards. In contrast, Australia (women) have lower game possession, lower entropy in the attacking half and lower circle possession, and concede high opposition possession in their attacking half. However, Australia's ability to absorb pressure and counter attack led them to the final of the 2019 Pro League tournament against Netherlands. The opposing strategies reflects the need to analyse teams individually as there is more than one way to win a game of hockey and teams must develop strategies that reflect the abilities of their players.

In conclusion, attacking and defensive ball movement profiles in international field hockey have been developed using video and notational analysis. These profiles highlight the direction and unpredictability of a team's ball movements and the attacking opportunities that arise. The ability to quickly get the ball to and then maintain possession in the attacking half using a variety of patterns are key factors in developing effective strategies. Teams able to execute strategies that exploit these factors are more likely to create greater attacking opportunities and be successful. This approach provides important evidence for coaches to develop strategies that utilises their team's strengths and exploits the opposition's weaknesses.

5.7 References

1. Sunderland C, Bussell C, Atkinson G, Alltree R, Kates M. Patterns of play and goals scored in international standard women's field-hockey. Int J Perform Anal Sport. 2006; 6:13-29.
2. Stöckl M, Morgan S. Visualization and analysis of spatial characteristics of attacks in field hockey. Int J Perform Anal Sport. 2013; 13:160-178.
3. Piñeiro R, Molinuevo JS, Román IR. Differences between international men's and women's teams in the strategic action of the penalty corner in field hockey. Int J Perform Anal Sport. 2007; 7:67-83.
4. Neuman Y, Israeli N, Vilenchik D, Cohen Y. The adaptive behavior of a soccer team: An entropy-based analysis. Entropy. 2018; 20:1-12.
5. Hobbs W, Morgan S, Gorman AD, Mooney M, Freeston J. Playing unpredictably: Measuring the entropy of ball trajectories in international women's basketball. Int J Perform Anal Sport. 2018; 18:115-126.
6. Altman, DG. Practical Statistics for Medical Research. London: Chapman & Hall; 1991 p. 404.
7. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2020.
8. Hausser J, Strimmer K. Entropy inference and the James-Stein estimator, with application to nonlinear gene association networks. J Mach Learn Res. 2009; 10:1469-1484.
9. Bates D, Maechler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. J Stat Softw. 2015; 67, 1-48.
10. Benjamini Y, Hochberg Y. Controlling the false discovery rate: A practical and powerful approach to multiple testing. J R Stat Soc Series B (Methodol). 1995; 57:289-300.
11. Lenth RV. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.6.1. 2021.
12. Therneau T, Atkinson B. rpart: Recursive Partitioning and Regression Trees. R package version 4.1-15. 2019.
13. Kuhn M. caret: Classification and Regression Training. R package version 6.0-86. 2020.
14. Lago C. The influence of match location, quality of opposition, and match status on possession strategies in professional association football. J Sports Sci. 2009; 27:1463-1469.

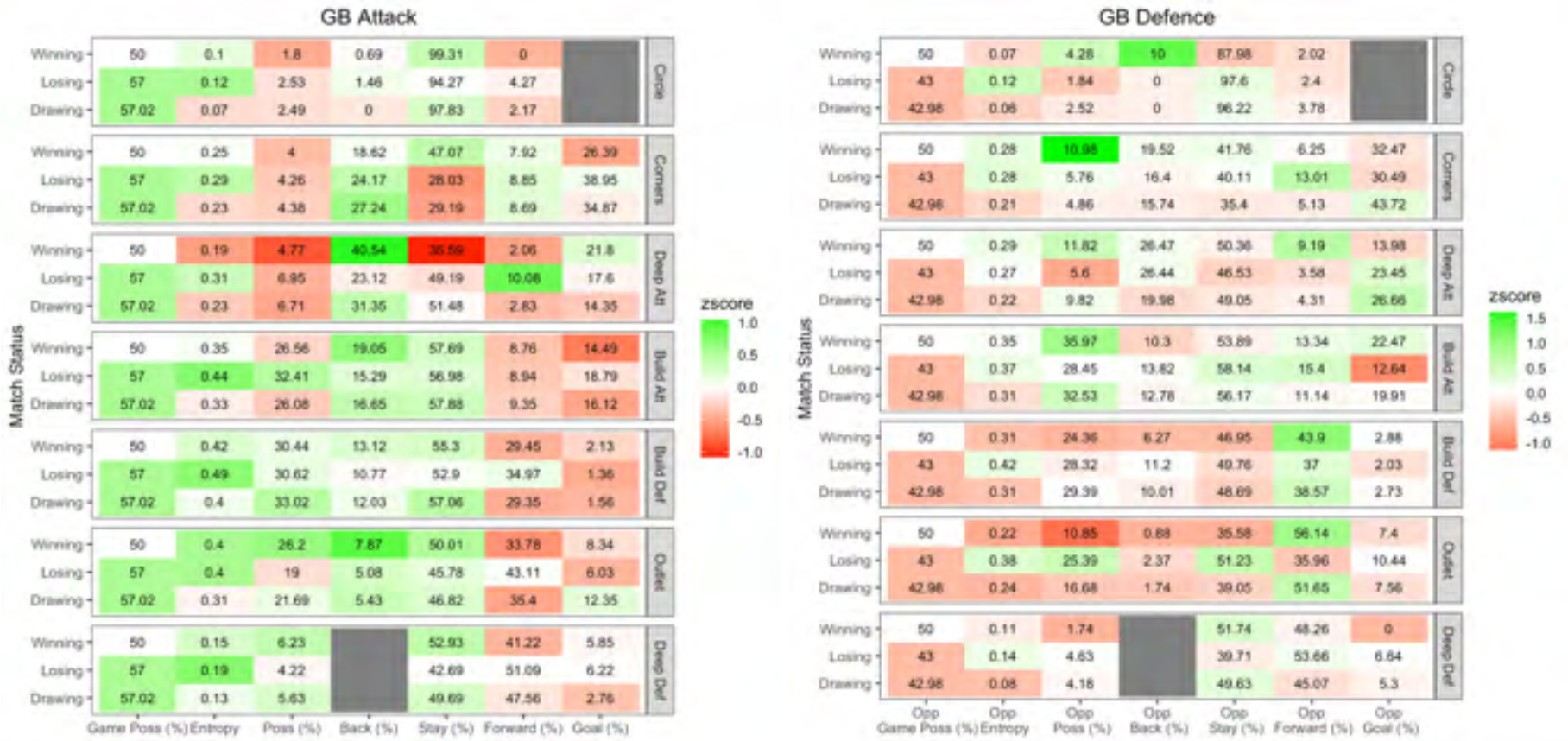
15. Lucey P, Bialkowski A, Carr P, Foote E, Matthews I. Characterizing multi-agent team behavior from partial team tracings: Evidence from the English Premier League. Proceedings of the AAAI Conference on Artificial Intelligence. 2012; 12:1387-1393.
16. Lord F, Pyne DB, Welvaert M, Mara JK. Field hockey from the performance analyst's perspective: A systematic review. Int J Sports Sci Coach. 2022; 17:220-232.
17. Gómez M-Á, Mitrotasios M, Armatas V, Lago-Penas C. Analysis of playing styles according to team quality and match location in Greek professional soccer. Int J Perform Anal Sport. 2018; 18:986-997.
18. Castellano J, Alvarez D, Figueira B, Coutinho D, Sampaio J. Identifying the effects from the quality of opposition in a football team positioning strategy. Int J Perform Anal Sport. 2013; 13:822-832.
19. Fernandez-Navarro J, Fradua L, Zubillaga A, McRobert AP. Influence of contextual variables on styles of play in soccer. Int J Perform Anal Sport. 2018; 18:423-436.
20. Tenga A, Ronglan LT, Bahr R. Measuring the effectiveness of offensive match-play in professional soccer. Eur J Sport Sci. 2010; 10:269-277.
21. D'Amour A, Cervone D, Bornn L, Goldsberry K. Move or die: How ball movement creates open shots in the NBA. MIT Sloan Sports Analytics Conference. Boston, USA. 2015.

5.8 Supplementary Resources

Supplementary Resource 5.1 Attacking (left) and defensive (right) ball movement variables for Argentina men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.2 Attacking (left) and defensive (right) ball movement variables for Australia men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

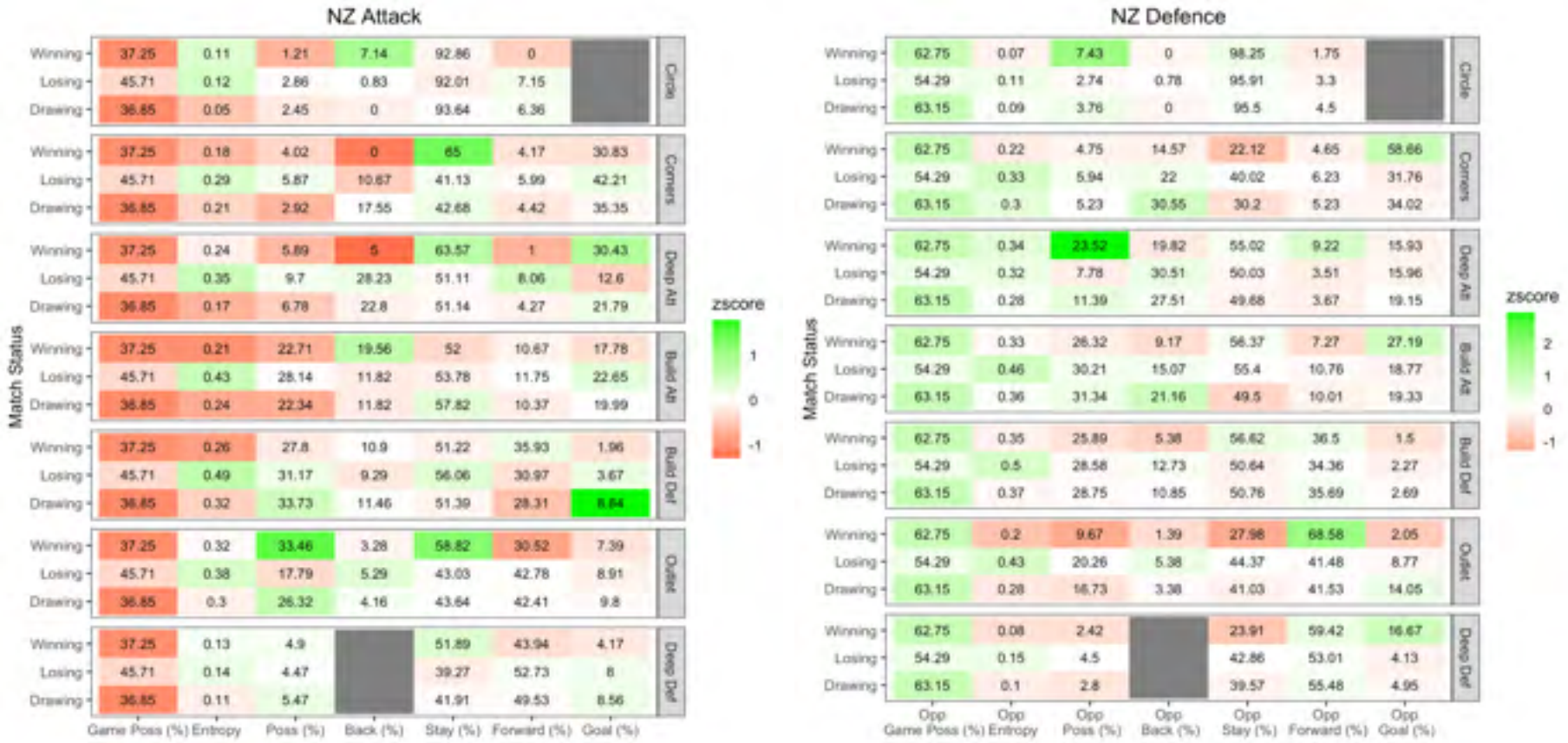
Supplementary Resource 5.3 Attacking (left) and defensive (right) ball movement variables for Belgium men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.



Supplementary Resource 5.4 Attacking (left) and defensive (right) ball movement variables for Great Britain men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

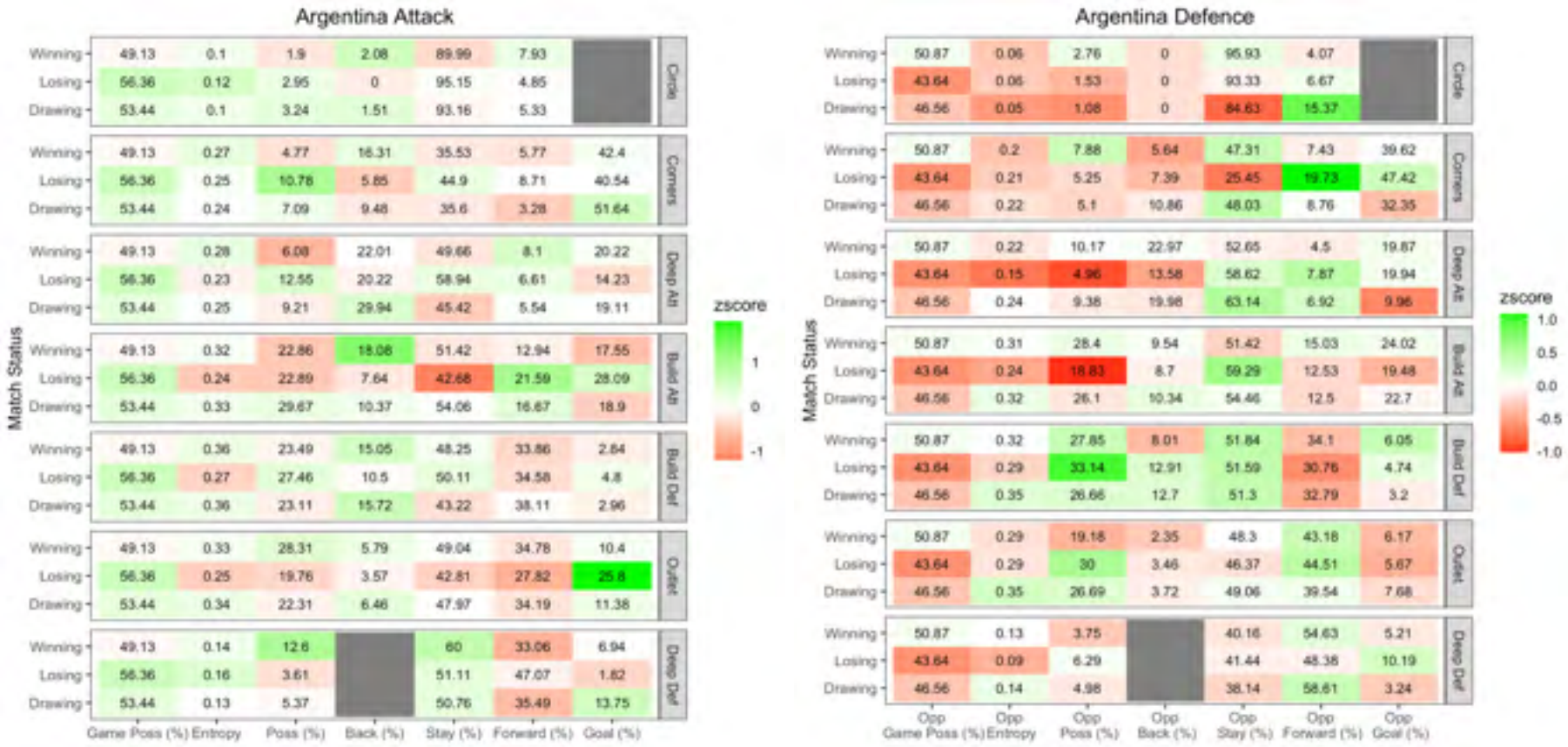
Supplementary Resource 5.5 Attacking (left) and defensive (right) ball movement variables for Germany men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.6 Attacking (left) and defensive (right) ball movement variables for Netherlands men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.



Supplementary Resource 5.7 Attacking (left) and defensive (right) ball movement variables for New Zealand men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

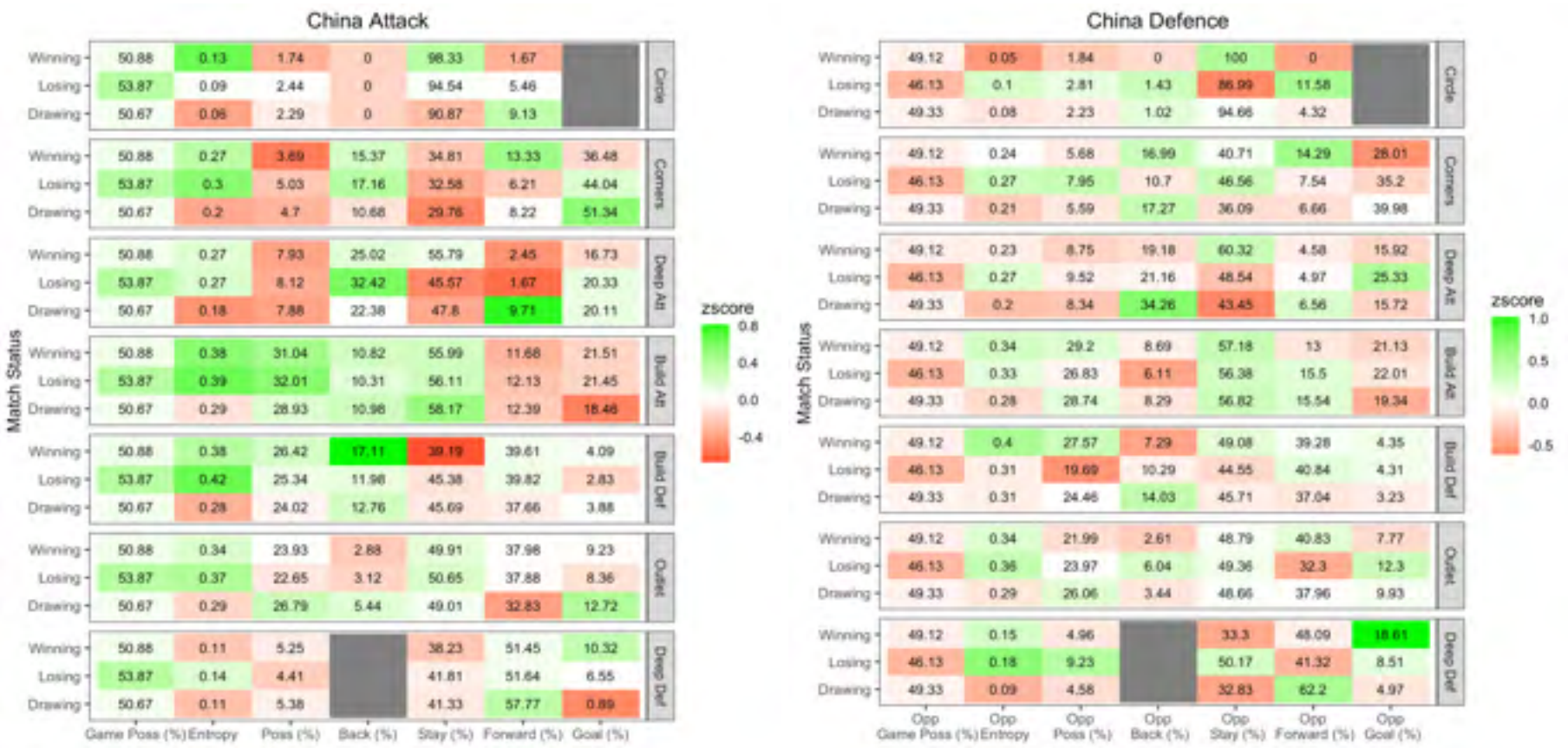
Supplementary Resource 5.8 Attacking (left) and defensive (right) ball movement variables for Spain men's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.



Supplementary Resource 5.9 Attacking (left) and defensive (right) ball movement variables for Argentina women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.10 Attacking (left) and defensive (right) ball movement variables for Australia women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.11 Attacking (left) and defensive (right) ball movement variables for Belgium women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

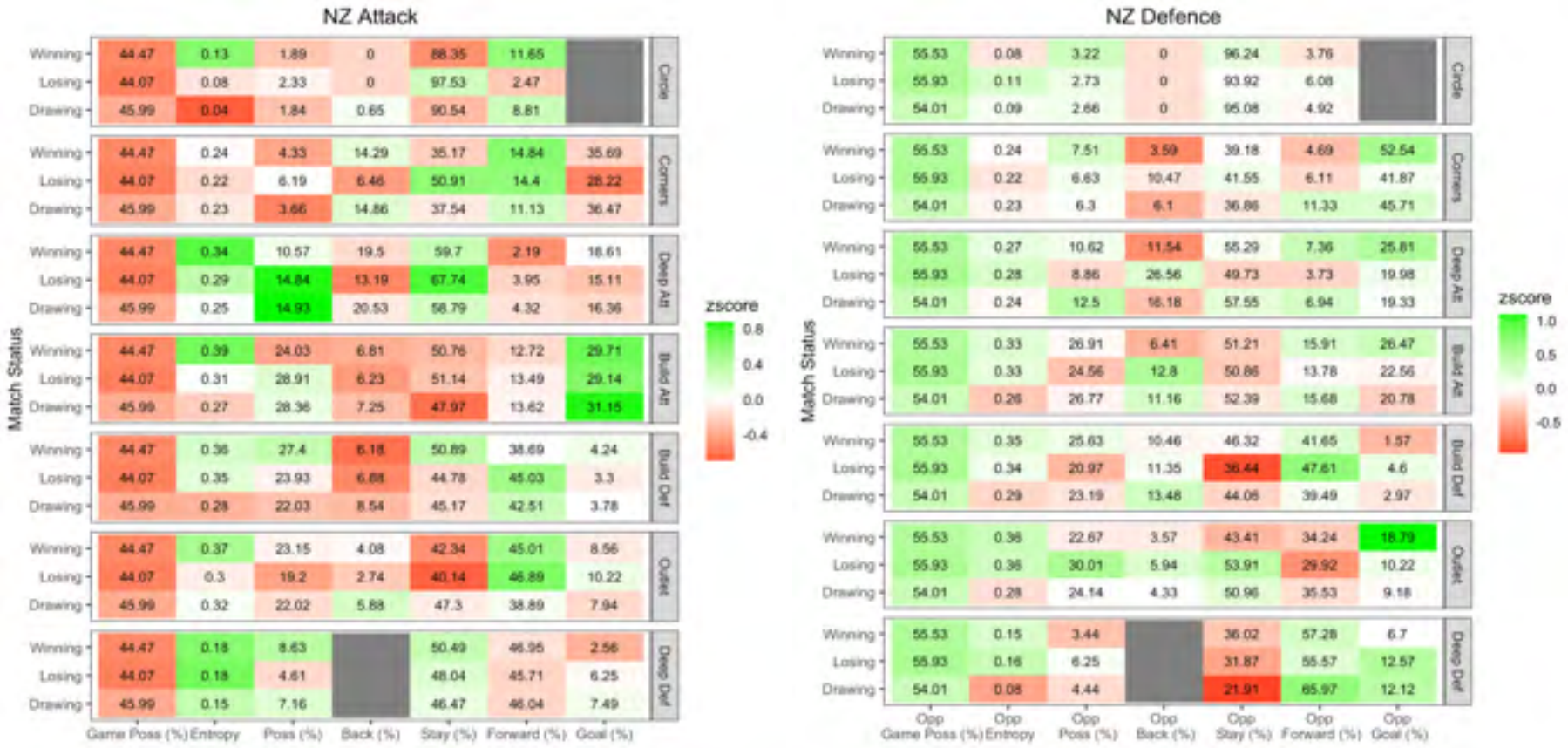


Supplementary Resource 5.12 Attacking (left) and defensive (right) ball movement variables for China women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.13 Attacking (left) and defensive (right) ball movement variables for Great Britain women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.14 Attacking (left) and defensive (right) ball movement variables for Germany women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.15 Attacking (left) and defensive (right) ball movement variables for Netherlands women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.



Supplementary Resource 5.16 Attacking (left) and defensive (right) ball movement variables for New Zealand women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Supplementary Resource 5.17 Attacking (left) and defensive (right) ball movement variables for United States of America women's team when winning, losing or drawing. Results are presented as average of ball movement variable on the x axis per match status per attacking zone on the y axis. Z-score indicates variables used more (green) and less (red) often than the league average.

Declaration of Co-Authorship for Thesis Chapter 6

DECLARATION BY CANDIDATE

In the case of Chapter 6 the nature and extent of my contribution to the work was the following:

Nature of Contribution	Extent of Contributions (%)
Study design, analysis and interpretation, manuscript preparation	80

The following co-authors contributed to the work:

Name	Nature of Contribution	Contributor is also a UC student (Yes/No)
Dr Jocelyn Mara	Design, analysis, editing	No
Prof David Pyne	Design, analysis, editing	No
Dr Marijke Welvaert	Design, analysis, editing	No

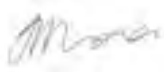
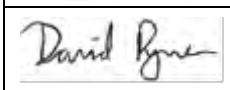
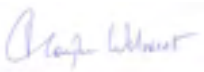
09/08/22

Candidate's Signature Date

DECLARATION BY CO-AUTHORS

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: Research Institute for Sport and Exercise, University of Canberra

Signatures	Date
	09/08/22
	09/08/22
	09/08/22

Chapter 6 - Capture, Analyse, Visualise: an exemplar of performance analysis in practice in field hockey

Lord F, Pyne DB, Welvaert M, Mara JK. (2022) Capture, Analyse, Visualise: an exemplar of performance analysis in practice in field hockey. *PLoS One* 17: e0268171. https://doi.org/10.1371/journal.pone.0268171

Abstract

The goal of performance analysis is to capture the multitude of factors that affect sports strategy, and present them in an informative, interpretable, and accessible format. The aim of this study was to outline a performance analysis process in field hockey that captures, analyses and visualises strategy in layers of detail culminating in the creation of an RStudio Shiny application. Computerised notational analysis systems were developed to capture in-game events and ball tracking data of 74 matches from the Women's Pro League 2019. Game styles were developed using k-means cluster analysis to reduce detailed in-game events into practical profiles to identify the attack types, game actions and tempo of a team's strategy. Ball movement profiles were developed to identify the predictability (entropy) and direction (progression rates) of ball movements, and consequent distribution of possession in different attacking zones. The Shiny application, an interactive web-platform, links the information from simple game profiles with detailed game variables to understand each teams' holistic game plan, how they are different, and how to exploit these differences. The process outlined can be applied to any team invasion sport to understand, develop and communicate successful strategies under different match situations.

Key words: strategy, sports analytics, team invasion sport, data visualisation

6.1 Introduction

Performance analysis is used to provide insight into tactics and strategy to help sport coaches understand how and why outcomes occurred to improve future performance. A large proportion of performance analysis research has focused on identifying differences between successful and less successful teams to identify key performance indicators [1]. These key performance indicators then become the benchmark a team needs to achieve to win a game or tournament [1]. However, outcome-orientated performance indicators only report *what* happened. There is more than one way to win a game and these simple performance indicators don't provide insight into *how* a team achieved these outcomes. Here we focus on process-oriented performance analysis in team invasion sports to provide effective insights into team and coaching strategy.

The main processes in performance analysis are data capture, analysis, visualisation and communication [2]. Appropriate methods must be utilised in each step to ensure the effective communication and translation of practical insights into strategy. To understand team strategy an analyst and coach must understand what a team is trying to achieve, how they go about achieving it, and the technical-tactical elements that contribute to each step. Therefore, performance analysis should capture, analyse, and visualise multiple layers of information. This approach ranges from detailed nuances of teams that help form the building blocks of a strategy, to practical identities that reflect key aspects of performance that can be observed and communicated to players.

Team invasion sports are considered to be dynamic, complex systems [3-6]. A dynamic, complex system reflects an environment with multiple interacting factors that are constantly changing [7]. To provide effective and practical insight into strategy, it is essential to capture in-game events in high detail to replicate the multitude of interacting elements that affect each action and outcome in a game. When analysing data, it is important to generate insights within the context of a moment in a game, and to present the data in meaningful ways that facilitate the development of strategy. This approach means placing greater focus on the issues of *how* and *why* in relation to outcomes. Advancements in technology, such as computerised notational analysis systems and semi-automated tracking systems, have allowed a greater amount of detail to be captured with more emphasis on spatio-temporal variables and opposition interactions [8]. Implementation of data science software and analytic methods has accommodated the increasing number of data points captured per game,

and dimension reduction techniques are often employed to reduce large, complex data sets into simple, practical profiles [1].

The field of performance analysis has evolved with changing technologies and perspectives, and there is growing interest in each step of the process in research. Key elements include validating data capture tools [9-10], analysing data to identify game styles [11-13] and describing visualisation tools for live game events [14-16]. However, there is often a disconnect between research and practice with limited guidelines and tools to facilitate a clear and effective approach for conducting performance analysis in the real world. In practice, data capture, analysis and visualisation must occur cyclically. Constraints such as limited resources and time restrictions are imposed, and this process must analyse both the team behaviours in regard to the outcome of a match, and the trends occurring in a tournament or season. Collectively these challenges may limit the effective communication of strategy in team invasion sports.

The aim of this study was to outline a performance analysis process, from data capture to communication, in field hockey for developing and communicating strategy in preparation for upcoming games. The secondary aim was to develop a Shiny application in RStudio (https://shiny.rstudio.com) to illustrate how strategy can be communicated. Data capture was completed with a computerised notational system, and data analysis and visualisation conducted using programming software. Here we provide access to data analysis and visualisation code to demonstrate the technical aspects involved so the process may be reproduced and applied to other sports or tournaments. This process utilises contemporary and emerging analytic techniques that can be completed with limited resources. The key concepts in capturing, analysing, and visualising data can be applied to any team invasion sport. No other study has detailed the process from start to finish so this study showcases the pathway from research to practice in performance analysis and data visualisation.

6.2 Design Considerations

6.2.1 Data Capture

The development of computerised notational analysis systems allows games to be analysed retrospectively, and video to be paused and rewound to ensure a high volume of data is captured accurately. Information is captured using a “code window” that includes code and label buttons. All actions and events deemed important to answer a predetermined question are recommended to be included as a code button. Labels can be added to code rows as

descriptions allowing layers of contextual information to be recorded per event. When a code button is clicked it generates an instance in a separate row in the timeline (Figure 6.1A). Code rows could range from general to specific, such as a whole possession to an individual game action, so layers of analysis can be easily extracted and analysed. When a label button is clicked the descriptive information is placed in the linked code rows. It is suggested to include labels describing each game event per time, space, opposition and match context, in all code rows.

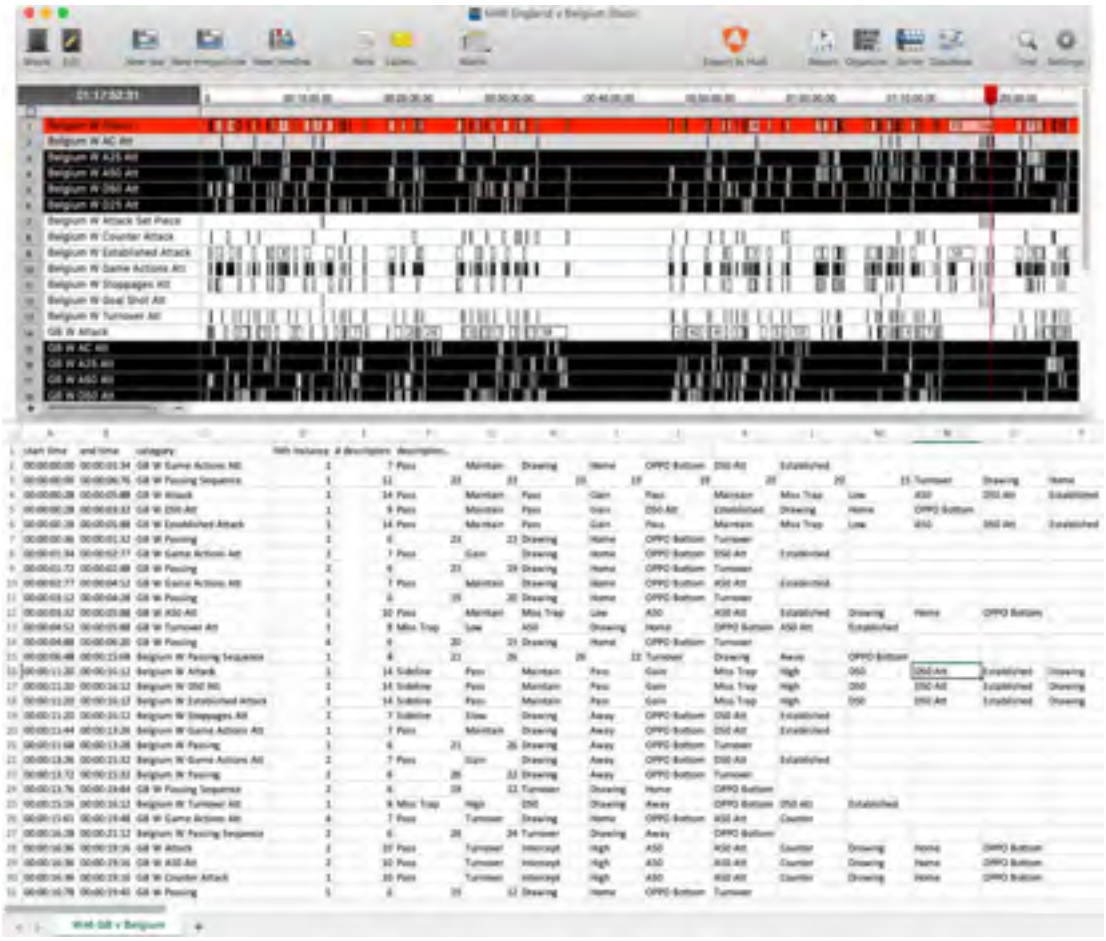


Figure 6.1A. Example of a timeline of coded events in SportsCode. Each row represents a coded event with each rectangle within a row reflecting an individual instance of that event and includes all descriptive labels. **B.** XML output of example timeline, displayed in Microsoft Excel, each row represents an instance from a code row (category column) and all included descriptive labels (from descriptors column).

Before capturing data, the validity of code windows should be assessed to ensure variables captured can be interpreted accurately and notated reliably. Clear and unambiguous definitions must be presented for all descriptive variables to be analysed. When capturing spatial data, natural landmarks on the field, such as the halfway line or goal posts, can be used to divide the field into cells to make capturing the data more reliable. It is suggested that the size of the cells be the smallest dimension(s) that provides meaningful impact when moving between them, and considering the type of skills used to move the ball, and the length of passes achievable. Reliability of categorical variables should be assessed through inter- and intra-observer reliability tests to calculate kappa coefficients, indicating the degree of agreement between observers. A kappa coefficient should be >0.80 to ensure the data capture process is reliable [17].

6.2.2 Data Analysis

The aim of data analysis is to summarise the information captured across a period of time to uncover patterns or trends across games reflecting common strategies used by teams. To provide layers of detailed insight, information can be extracted from the raw data by analysing interactions between variables, and then condensed into practical profiles to reflect the holistic nature of sport [1]. Raw data can first be normalised by converting to a ratio or percentage [18]. Each variable can be divided by the total actions or events such as percentage of goal shots per attack type or ball movements per location, to provide context for the value and allow variables to be compared between games. However, this approach may be reconsidered if small sample sizes are utilised. If normalisation does occur, then the number of data points should also be presented. Capturing and analysing in-game events or ball movements in high detail permits targeted analysis for different phases of the game.

To condense highly detailed in-game event variables into a holistic game plan, clustering algorithms can be employed. Clustering algorithms, such as k-means clustering, factor analysis or self-organising maps, group games with similar patterns into clusters which represent different strategies occurring during a game. These patterns are deemed game styles which are defined as the consistent strategy implemented by a team [19]. This process is expediated by employing clustering algorithms using programming software, removing the need for the analyst to make these calculations manually. Data may be divided into predetermined categories to identify types of strategy within different components of the game such as the “moment of play framework” [19-20]. Alternatively, a clustering algorithm can determine the categories of performance [12, 13, 21]. Commonly used categories of

performance include game actions, attack types and tempo as they reflect the major ways in which a strategy can be manipulated.

It is recommended that variables included in the clustering model provide holistic insight into strategy. Variables that do not provide practically important differences between clusters should be omitted. A balance needs to be established between including highly detailed variables, and simplifying or generalising variables, so differences between game style types can be reported. Although individual nuances can be identified by studying a game event in high detail, they might not contribute to overall game style strategy. Similarly, condensing spatial data on ball movements into practical profiles requires areas of the field to be grouped by different phases of attack. This action allows cells on the field with similar purpose and outcomes to be clustered so strategies can be observed in different parts of the game that may be overlooked when viewed in high detail. The attacking zones should stem from deep in defence when a team is under high pressure, to building an attack and developing goal scoring opportunities. The shape and size of the zones must encompass the structure of a team and the types of ball movement occurring in each.

6.2.3 Data Visualisation and Communication

Visualisations should allow the viewer to identify trends and patterns at a glance without the viewer having to process large amounts of information [22]. They are the medium by which information on strategies will be communicated. Ineffective visualisations can lead to misinterpretation of data or confusion which limits the work completed to capture and analyse the data in practical ways. For visualisations to be impactful, it is suggested to present data in relation to a standard or reference value so that practical differences can be identified.

Visualisations can be manipulated by the geometry or type of figure used and the aesthetics of the elements in the figure [23]. Perceived aesthetics have been shown to be correlated with user engagement, where users were more likely to spend longer time studying a figure when the design of the visualisation was more pleasing to the eye [24]. Scatter plots can be used to show the relationship between two continuous variables, lines plots may be used to show continuous variables over time, and boxplots, histograms or raincloud plots can be used to present the distribution of continuous variables [25]. Comparatively, the distribution of discrete or categorical variables can be presented in bar plots, and the relationship between two categorical variables in a tile plot.

Aesthetics can be used to add additional dimensions or variables to a figure and include colour, size, and shape [26]. Colour can be used to highlight differences between variables. It is recommended to use a qualitative colour palette to differentiate categorical variables, with a distinct colour employed to separate each level of the variable. A sequential palette is suggested to be used for ordered numeric data, with colour increasing from light to dark to represent low to high numbers or values of greater importance. A divergent palette is advised for numeric values that include both positive and negative values and a central value. A divergent palette essentially contains two sequential palettes that merge in the middle to represent the central value, with lighter colours seen towards the middle and darker representing values further from the midpoint. A colour-blind friendly colour palette is recommended to enhance accessibility for all users. Size and shape can also be manipulated to emphasise different values with shapes identifying different categories and increasing shape size reflecting larger values or importance. Spatio-temporal data can also be presented using field (or court) diagrams to provide greater context to player or ball movements.

The medium in which the visualisations are presented also influences the insights being communicated. There is a trend away from static visualisations to dynamic web-based platforms given the ability for user interaction [27]. The ability to interact, explore and filter a data set through the visualisation can improve user engagement [28]. A greater depth of information can be presented in an interactive visualisation as layers of information can be displayed through manipulating the figures inputs. These figures are better able reflect the spatio-temporal and opposition influences on decisions and outcomes in team invasion sport. Accessibility to open-source programming environments such as RStudio has made it easier to produce effective interactive visualisations and share them online for improving communication and translating strategy in practice. These programs also allow the presentation of multiple related figures as a dashboard or application so the bigger picture can be understood by linking the key findings from each visual. When presenting a range of visualisations that revolve around the same theme, it is important to provide consistency between figures so a coach can focus on interpreting the results rather than trying to process the design of the figure. For example, providing a consistent colour palette for variables or unique levels of variables used multiple times (i.e., red indicates losing a match and green indicates winning), and having legends placed in the same location.

6.3 Methods

6.3.1 Data Capture

Video footage from 74 matches from the 2019 International Hockey Federation (FIH) Women's Pro League were analysed retrospectively using SportsCode (Version 11, Hudl, https://www.hudl.com), a computerised notational analysis software. Each game was reviewed twice to code for in-game events and ball movements separately. Kappa coefficients for intra- and inter-observer reliability tests were >0.86 for both code windows demonstrating that the data capture tools were reliable [29].

The code window used to analyse in-game events is displayed in Figure 6.2. Code rows (and their associated labels) included all user-defined major game events; game actions (types and movement effects), stoppages (types and restart speeds), turnovers (types, pressures, and locations) and goal shots (outcomes, pressures, and locations). These code rows also included attack types, field locations, match status, match location and quality of the opposition as labels. All game events and actions were labelled in a team possession code row and divided into attack type and field locations code rows. This process allowed a possession, attack type, field location, or specific game event to be easily and efficiently analysed in high detail using the descriptors of the code row in question.

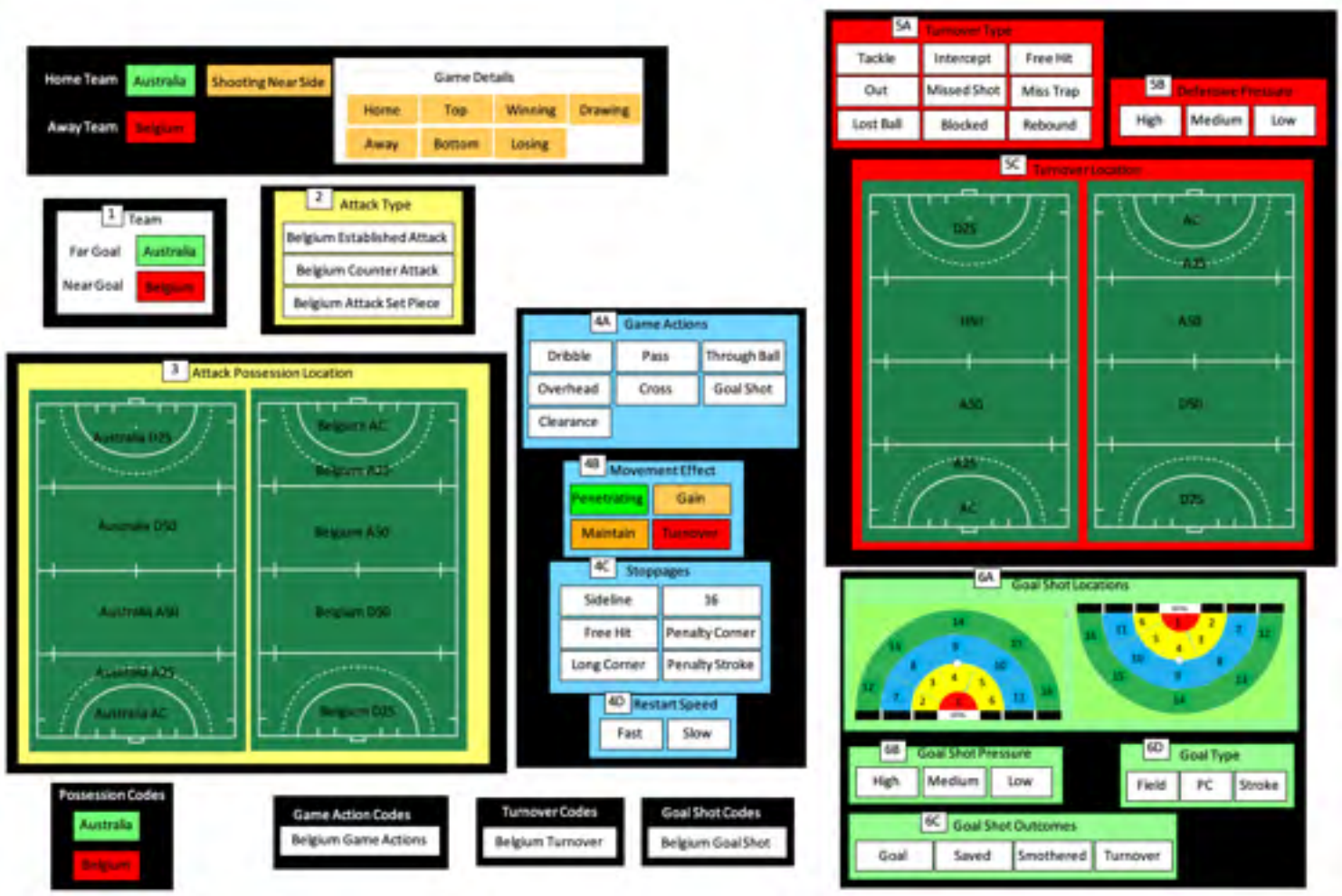


Figure 6.2 Notational analysis system used to capture game variables in SportsCode to create game styles. The numbered boxes illustrate the steps to follow to code a sequence of field hockey play by selecting the team in possession, attack type, field location, and then options for in game events available in boxes 4-6. The code window provides an example of a game between Australia (home team) and Belgium (away team).

The code window for tracking ball movement is illustrated in Figure 6.3. This window represents a field divided into 40 zones of equal size. Code rows included each individual ball movement and each possession sequence, and the start and end locations of each ball movement, play outcomes from a sequence of ball movements and match context labelled in each code row. This structure allowed overall ball movements or sequences of play to be analysed in relation to outcomes. The XML file for both in-game events and ball movements were then exported from SportsCode®, and then imported into Microsoft Excel® so that data could be analysed in another programme. The XML file (Figure 6.1B) contains all information recorded in chronological order, where each row of data represents an individual instance from a code row with descriptive labels and time stamp, indicating start and end times of the event, included.

Figure 6.3 Notational analysis system used to capture ball movement patterns in SportsCode showing an example field hockey game between Australia and Belgium. An analyst would choose the team in possession, the start and end location of each ball movement followed by the outcome at the end of a play. The field orientation would switch direction depending on which team was in possession so that cell 1 always corresponded to the attacking 25 left corner and cell 40 to the defensive 25 right corner of the field.

6.3.2 Data Analysis

Data analysis was completed in RStudio 1.3.1093 (RStudio Inc, https://www.rstudio.com), a statistical programming integrated development environment, using the R (version 4.03) programming language. The R code detailing the instructions on how to analyse game styles, ball movements and in-game events is available here (https://github.com/felicitylord/Hockey-Analysis). Alternatively, the R code and output is available at their respective hyperlinks

(game styles [https://rpubs.com/felicitylord/game-styles], ball movements [https://rpubs.com/felicitylord/ball-movements], in-game events [https://rpubs.com/felicitylord/in-game-events]) so that instructions can be viewed without access to RStudio. Each team per match per match status period (winning, losing, and drawing) were analysed separately to identify strategies used by individual teams under different match conditions. Attack profiles were produced when a team was in attack and defence profiles produced by analysing opposition values.

6.3.2.1 Game Styles

Normalised variables (calculated from their code row) included in the creation of game styles were:

- Game Actions: game action types per location per attack type (%), ratio of movement effects per location per attack type, time per attack type per location, game action totals per attack type
- Stoppages: stoppages per location (%), stoppages per attack type (%), restart speed ratios per location per attack type, set pieces per attack type (%)
- Turnovers: turnovers per attack type (%), turnover types per attack type (%), turnover locations per attack type (%), turnover pressures per attack type (%)
- Goal shots: goal shots per attack type, goals per attack type
- Attack type: number per game

To identify game styles in this study, 102 dynamic game variables were divided into 6 predetermined game style categories which consisted of: 1) Established Attack Game Actions, 2) Counter Attack Game Actions, 3) Established Attack Success, 4) Counter Attack Success, 5) Set Piece Occurrence, and 6) Tempo. A k-means cluster analysis was performed on each category using the '*kmeans'* function from the *'stats'* R package [30]. The number of clusters chosen should be the largest amount that reduces the variation between clusters, and reflects the common strategies or outcomes in a category of performance.

For this study, 2 clusters were selected per game style category and practical identities given to each that described the different approaches so strategy could be easily communicated. Game style types included strong or poor for established and counter attack success, high or low for set piece occurrence, pass or dribble for established and counter attack game actions and direct or possession for tempo. Bootstrapping, using the *'clusterboot'* function from the *'fpc'* package [31] was undertaken to assess reliability, with >75% of iterations produced

consistently. A game style profile was produced by calculating the percentage of games within each game style type. This process reliably reduced the data from 102 dynamic game variables to 6 key categories of performance that reflect how a team plays and areas of strength and weakness.

6.3.2.2 Ball Movements

The information gained from ball tracking data was converted from locations on the field to represent where a team had possession, how unpredictable a team was in their movements, and the direction of ball movements in different areas of the field. Data was simplified from 40 cells into 7 attacking zones, which are illustrated in Figure 6.4, to represent different phases of play. The variables analysed for each attacking zone included:

- Possession - the time to complete ball movements
- Standardised Entropy - a measure of unpredictability of a ball movement from one cell to all other cells on the field
- Progression rates - the percentage of ball movements in each direction between attack zones; back, stay (within a zone), forward, goal (more direct to goal)
- Game possession - the total number of ball movements in all attacking zones between teams for each match

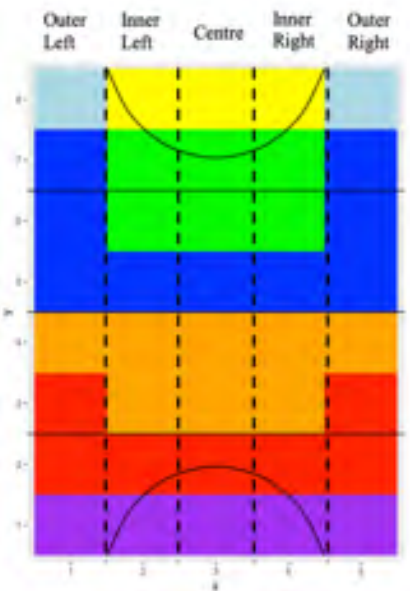


Figure 6.4 Field hockey pitch divided into seven attacking zones; yellow = circle, light blue = corners, green = deep attack, dark blue = build attack, orange = build defence, red = outlet, purple = deep defence.

6.3.2.3 In-Game Events

The data capture process in this study allowed further analysis of in-game events including:

- Movement effects per game action type per attack type
- Goal shot locations, outcomes, and efficiencies
- Penalty corner routines and outcomes
- Stoppage types per location
- Turnover types per location
- Possession time, length, and rate
- Starting locations per attack type
- End locations per start location per attack type

These variables were excluded from the game styles analysis given a lack of variation between game style types however individual team differences can be observed. Data analysis involved calculating percentages for each outcome or type of action. Including a separate code row for each variable for analysis, permitted simple extraction of the required information, and calculation of totals by counting the number of instances within a code row, and subsequent conversion to percentages.

6.3.3 Data Visualisation and Communication

Data visualisation was completed in RStudio to create an interactive application, called a Shiny app, to aggregate all data analysis into one product. A Shiny app, created using the '*shiny*' R package [32], is composed of a user interface (ui) file which controls the design and appearance of the app, and a server file which contains the instructions to generate the visualisations. The final product is an interactive web application which allows a user (such as a coach or player) to view the results on a web browser, without needing specific software or expertise. The ui and server files, illustrating the design and creation of figures, are detailed here (https://github.com/felicitylord/Hockey-Analysis).

Figure 6.5 illustrates the design of the app. The application is divided into 4 tabs at the top of the page using the '*navbarPage'* function including a page describing how to use and interpret the results, and then separate tabs for game styles, ball movements and in-game events. Within each tab, a list of sub-categories of visualisations are presented, using the '*navlistPanel'* function, along the left-hand side as a side panel. Each sub-category contains a list of figures available to analyse for that topic using the '*navbarMenu'* function. A practical

feature of Shiny apps is the ability to interact with the data using '*reactive'* functions. These functions filter the data to the chosen criteria which automatically updates the figures. Consequently, multiple figures are not needed to be produced per team or context as an individual figure can easily be manipulated to compare different situations. The main panel of the app displays the visualisation and filter options available. For example, in this app, a coach can choose the team, match status, field location or attack type to analyse.
Team data is presented as an average in comparison to the league average so that strengths and weaknesses, and similarities and differences, can be identified. Z-scores (normalised standard deviation from the mean) are also used to reflect the magnitude of differences when comparing variables on different scales. All figures are produced using the '*ggplot'* function from the *'ggplot2'* R package [33]. Within this function the type of plot produced must be specified. Tile plots and heat maps are produced using '*geom_tile'*, columns charts with '*geom_col'* and scatterplots with '*geom_point'*. To display the visualisation in the app, the *'renderPlot'* function is specified in the ui file.

Figure 6.5 Shiny application layout. Tabs are outlined in red, side panel and subcategory list in blue and filter options in green above the visualisation.

6.4 Results

Access to the application created to visualise data analysing strategy in hockey is available at this hyperlink (https://felicity4.shinyapps.io/Hockey101/). The Shiny app is deployed using an external server hosted by RStudio (https://shinyapps.io) which allows users to view and interact with the application without needing access to RStudio. Examples of each type of visualisation are provided to illustrate how figure types and aesthetics have been used to communicate different parts of strategy. Figure 6.6 illustrates an example of a game style profile, Figure 6.7 shows an example of a game style categories variables, Figure 6.8

illustrates game style types per match outcome, Figure 6.9 displays goals for and against per match, Figure 6.10 illustrates a ball movement profile, Figure 6.11 displays heat maps for possession, entropy and progression rates, Figure 6.12 details an example in-game event profile for movement effects per game action and Figure 6.13 shows a goal shot map.

6.5 Data Interpretation

The Shiny app produces layers of simple to detailed visualisations that provide insight into understanding, developing and communicating strategy for individual teams in different match situations. The first layer of analysis provides insight into the holistic game plan and reflects key attributes of the game a coach can observe and communicate (Figures 6.6 and 6.10). The second level of analysis identifies differences and weaknesses in a team's strategy by breaking down the key attributes into their contributing parts, and understanding how the holistic strategy is achieved (Figures 6.7 - 6.9, 6.11). The third level of analysis identifies ways of exploiting opposition weaknesses and inhibiting opposition strengths, and provides the detail to develop strategy by linking the techno-tactical indicators with the holistic game plan (Figures 6.12 and 6.13). The process to analyse strategy is outlined by describing the information that can be gained from each visualisation, and how it relates to strategy development through interpreting hypothetical scenarios.

The initial visualisation to analyse is a game style profile (Figure 6.6). Game style profiles allow easy communication of strategy as they reflect the key attributes a team consistently implements in practical terms. The key aspects of performance include how a team moves the ball, how strong they are in different attack types, and their ability or intent to control the ball. These form the basic elements of all team invasion sports, and their interactions describe the strategies implemented by teams. Common strategies emerge from analysing these interactions. For example, hockey teams strong in established attacks using a possession approach like to control the game, but teams strong in counter attacks who play direct prefer attacking quickly while the opposition is unbalanced. Alternatively, a team strong in established attack, but poor in established defence, creates and concedes high attacking opportunities by playing a high-risk game looking to outscore the opponent. In contrast, a team poor in established attack, but strong in established defence, creates and concedes few attacking opportunities by playing a safer strategy prioritising defence over attack.

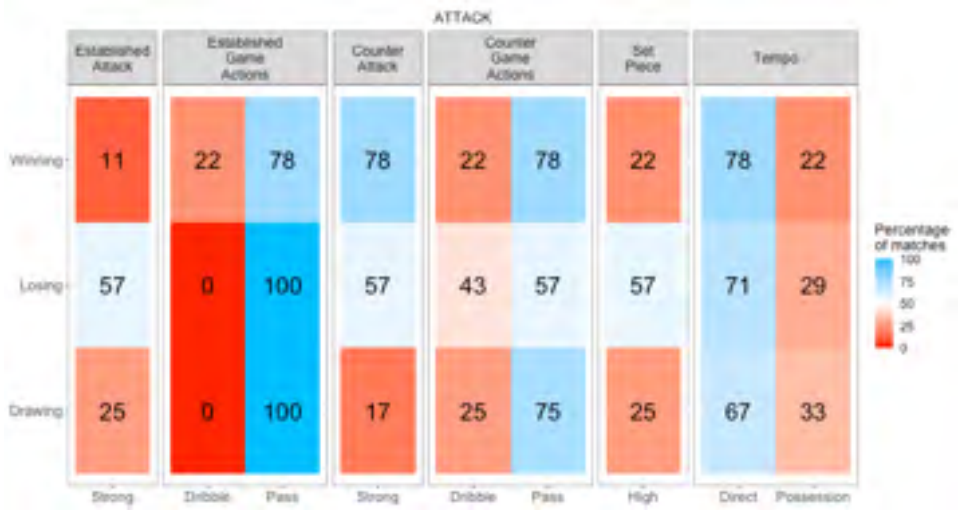


Figure 6.6 Attack game style profile illustrating percentage of matches in each game style type grouped by game style category on the x axis per match status on the y axis. Red shading indicates a game style used rarely, white an inconsistent game style and blue a consistent game style.

After identifying a team's game style type for each category of performance, an analyst can dive deeper into the variables relating to each game style type to understand why a team is classified this way (Figure 6.7). This second layer of analysis evaluates the game variables that generate a game style type, and identifies the individual nuances separating teams with similar game styles. If a team average is equal to or above the league average for a game variable within their game style type, this style should be monitored during a game to identify if a team is executing their preferred strategy. However, a team identifying with a variable in the opposite game style type indicates a difference in their strategy compared to other teams. Furthermore, if a team average is centred between game style types it indicates a variable that is inconsistent between matches. For example, a team may be classed as using a direct game style, typically classified by fewer game actions per game and possession but a higher number of established and counter attacks per game. However, this team records fewer counter attacks per game (a variable associated with a possession game style) indicating that although they want to attack directly, as they may not have the skills to control the ball for long periods of time, attacking with a balanced line up is preferred. This scenario places the team in a better position defensively as they are more likely to have greater numbers around the ball when they do turn it over.

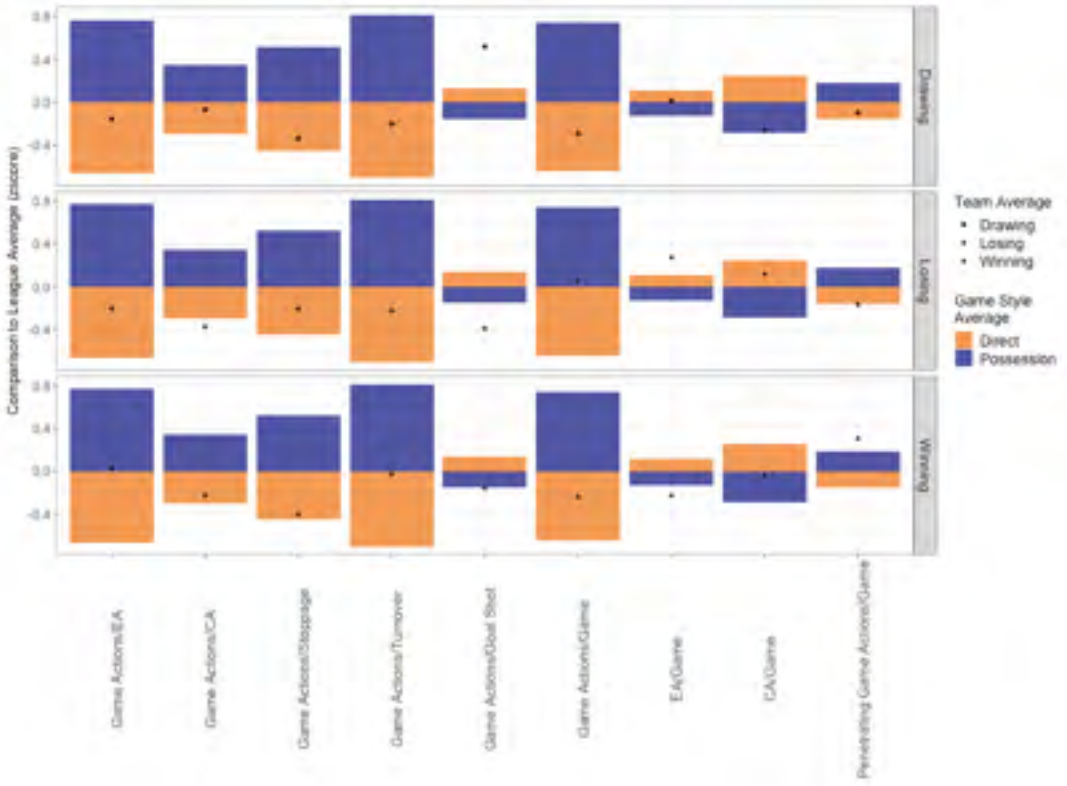


Figure 6.7 Variables included in the tempo game style category. Game variables are presented on the x axis and z-scores per match status on the y axis. Bars represent average values for each game style type (direct or possession) and shapes represent team averages per match status. A team average of 0 indicates an inconsistent variable for that game style as it does not strongly reflect either game style type, for example Game Actions/EA when winning. A team average within the game style bar reflects variables reflecting their game style type, for example Game Actions/Stoppage. A team average that is greater than the game style average indicates a variable strongly related to the game style type, for example Game Actions/Goal Shot when drawing. A team average that is within the opposite game style type bar reflects a variable differentiating the team from teams using the same game style type, for example EA/Game when winning is classed as a possession characteristic but the team is classed as a direct game style overall.

An analyst may then evaluate game styles per match (Figure 6.8) and identify effective strategies each team used by relating match status and match outcomes. For example, game style types used during periods when a team were drawing could be deemed successful if this team consequently went on to win the match. However, if a team were losing and eventually lost the match, these tactics were not effective. Additionally, analysing goal differences (Figure 6.9) in relation to game styles per match outcome indicates the effectiveness of the strategies implemented, and the intent of teams to continue attacking or maintain a lead. For example, teams that consistently win low scoring games may be strong defensively, but average offensively, so they will look to protect a lead if they get ahead. Comparatively, a team that win games by a large margin may be strong in both attack and defence, so they will continue to seek goal scoring opportunities.

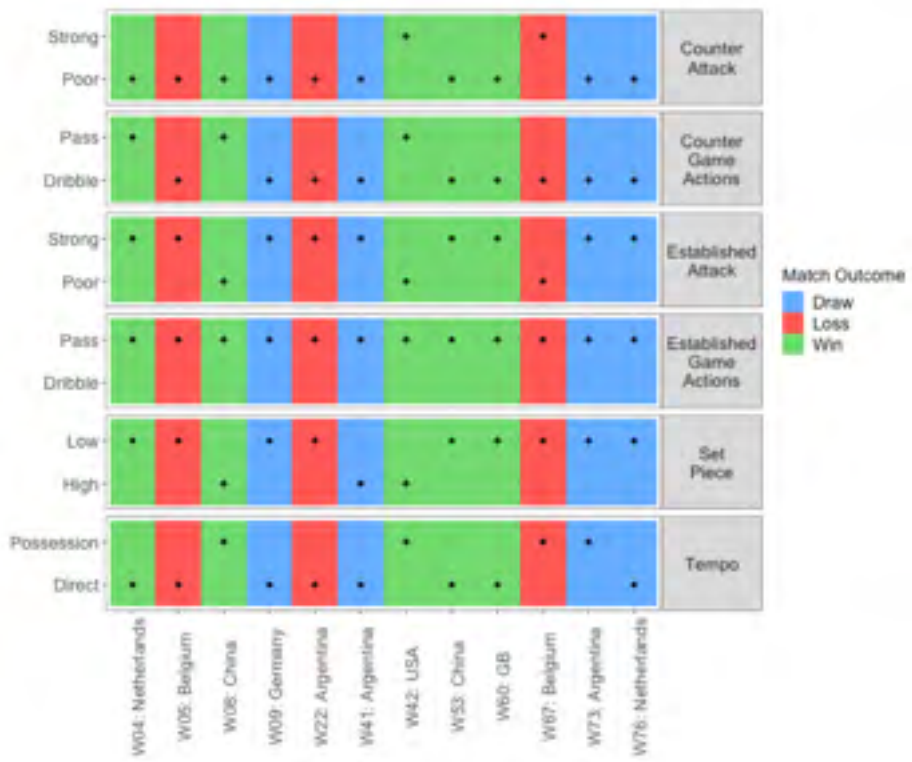


Figure 6.8 Game style types per match outcomes. Match per opponent are presented on the x axis and game style types per game style category on the y axis. Background colours indicate match outcome, blue indicates a draw, red a loss and green a win. The game style type used per match is indicated by a black dot.

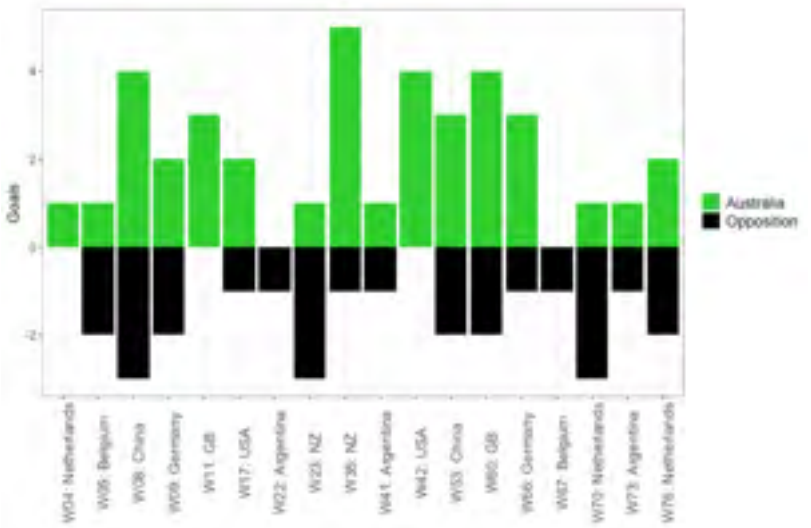


Figure 6.9 Goals for and against per match. Match per opposition are presented on the x axis, and goals for the reference team on the positive y axis in green and goals for the opposition on the negative y axis in black.

Ball movement profiles (Figure 6.10) provide a complementary insight into a team's game style, providing easy-to-communicate analysis by simplifying ball tracking information into practical descriptors. These profiles can further describe how a team moves the ball from a spatial perspective by analysing how much game control a team has, the predictability and direction of this movement, and the length of possession and opportunities within an attacking zone. Common ball movement strategies can also be identified; for example, a team with high entropy and possession in the attacking half with average progression rates attempt to control possession by utilising the length and width of the field. In contrast, a team with low entropy but high possession and forward movements in the attacking half can create a greater number of opportunities at goal by playing quickly and directly in attack.

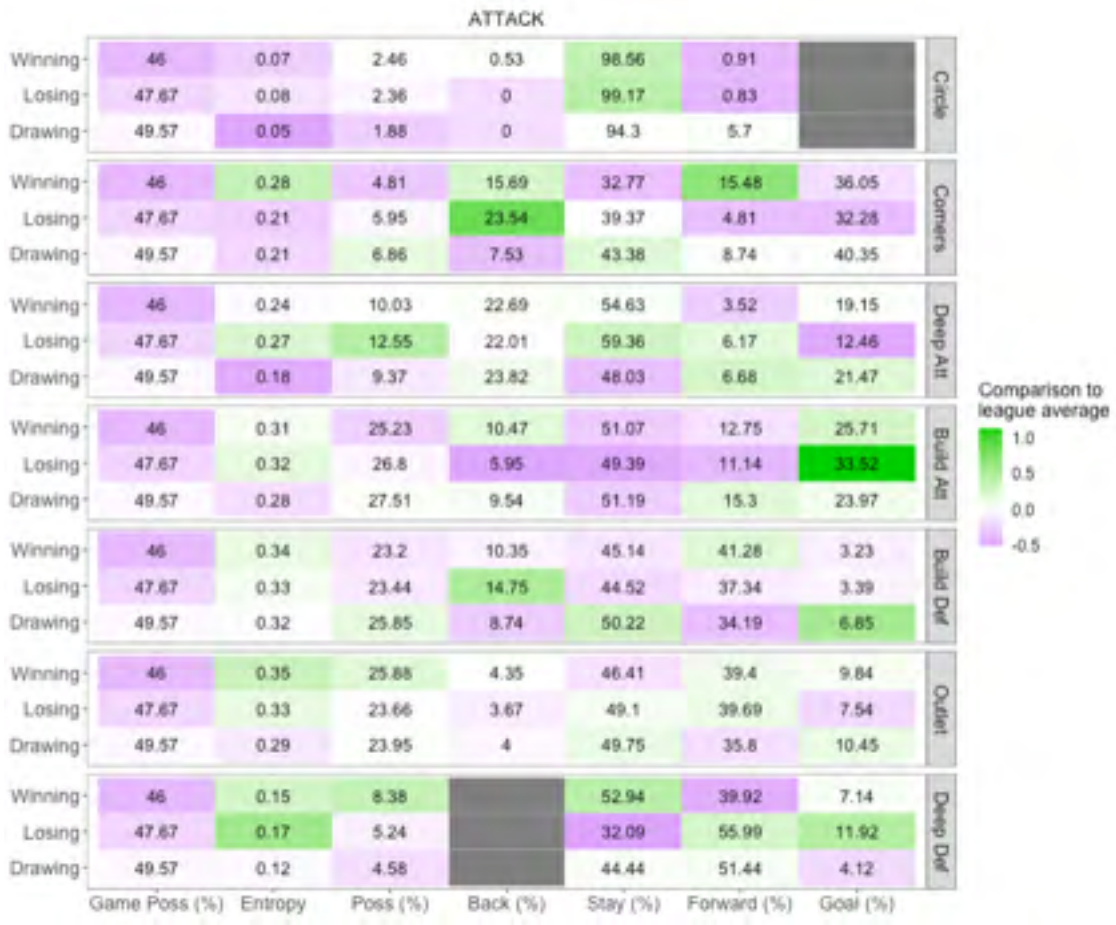


Figure 6.10 Attack ball movement profile illustrating ball movement variable on the x axis per match status per attacking zone on the y axis. Colour scale represents z-scores, purple shading indicates variables that are below average, white average and green above average performance compared to the league.

By understanding the ball movement style, an analyst can then observe specific areas of the field using heat maps (Figure 6.11). Heat maps allow easy interpretation of key areas on the field to provide insight into whether teams are more likely to use one side of the field, the inner or outer channels or through the centre. This second layer analysis also indicates how a team is structured in different phases of the game allowing specific plays to be developed to counteract the oppositions likely movements. For example, a team that has a higher percentage of possession in build defence on the outer and centre channels indicates the team likely plays with a back three, as opposed to higher possession in the inner channels evidence of a team playing with two central and two wing defenders.

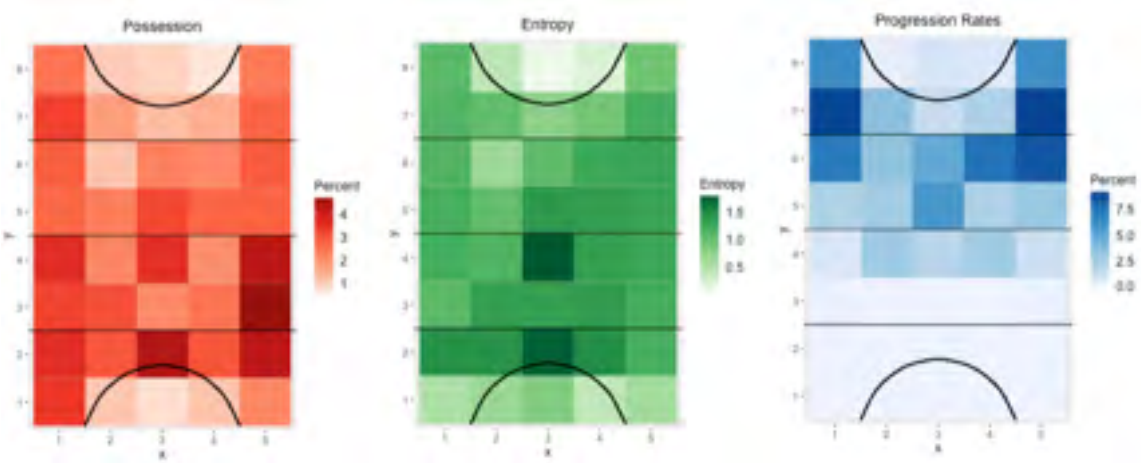


Figure 6.11 Heat maps illustrating possession (left), entropy (middle) and progression rates (right) with teams attacking towards the top of the figure. Light to dark colour scales indicate low to high levels of the variable. Each x/y coordinate represents one cell from the data capture process.

In-game descriptive events from game styles analysis and spatial data from ball movement patterns can be linked to help explain differences in strategy. For example, a team can be strong in established attack as they have greater actions and events in the attacking half, however they create fewer goal shots than average for this game style type. By observing ball movement profiles, it can be identified this team has greater possession in the build attack zone and corners, with heat maps illustrating a greater likelihood of transferring the ball around the midfield and through the left corner to enter the circle. This pattern allows the opposition to prevent goal shots by setting up in advantageous positions to goal. The interaction of these two types of analysis allows the *how* and *where* information of ball movement to be linked to provide greater insight into a team's success.

Studying in-game events provides a third layer of analysis on specific phases or events during a game, and breaks down the components a strategy is built around (Figures 6.12 and 6.13). This approach provides insight into how to exploit weaknesses or differences identified in game style or ball movement variables. This third level of analysis provides meaning behind the strategy rather than simply identifying the underlying team strategy. Understanding the overall plan for a team makes it is easier to understand how each component relates to this strategy. This is certainly the case compared to trying to understand a collection of detailed instructions without knowing the desired outcome. For example, (1) game style analysis reveals a team is strong in established attacks and prefers dribbling, (2) analysis of game variables of the established attack game style category shows this team records a higher percentage of penalty corners and less goal shots, and (3) analysing in-game events identifies a team is more likely to maintain possession when dribbling, than gain ground, and have a higher percentage of stoppages as free hits in the attacking 25. These three layers of analysis reflect a team strategy that aims to control possession, rather than attack the goals, and engage in individual contests to win free hits. Defensively to counteract this strategy, a coach would select players with high tackling ability and who can implement a zone defence, rather than man-on-man marking, to force the opposition to play around them rather than through them, to limit their opportunities for penalty corners as their preferred goal scoring method.

As another example, a team is identified as having lower possession, lower entropy and higher forward movements in the build defence zone. Heat maps can be used to reveal this team is more likely to move the ball down the outer edges of the field using long passes. Analysis of in-game events identifies this team has a greater percentage of turnovers from intercepts and out of bounds. Therefore, this team's strategy is to attack quickly but predictably in the forward direction, and risk long passes to get behind lines of the defence into space. A coach can instruct their forwards and midfield to exert high pressure on the ball carrier, and their defenders to play in front of their opposition strikers, and protect the dangerous passing channels. These tactics should force the opposition to throw riskier long passes with a greater chance of a turnover occurring, or pass short or dribble through the opposition which does not suit their abilities.

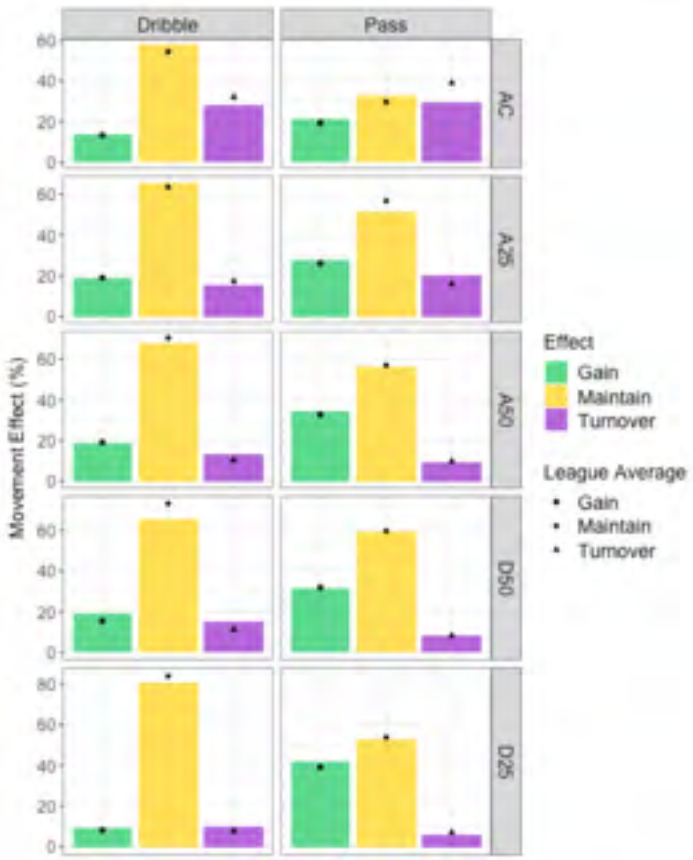


Figure 6.12 An example of in-game events visualisation illustrating dribble and pass game actions on the x axis per movement effect per field location on the y axis. Coloured bars indicate team average per movement effect, and shapes indicate league average per movement effect. Team performance is greater than the league when the bar is greater than the shape, and less than the league when the bar is lower than the shape. For example, this team is less likely to turn over the ball when dribbling in AC (attacking circle).

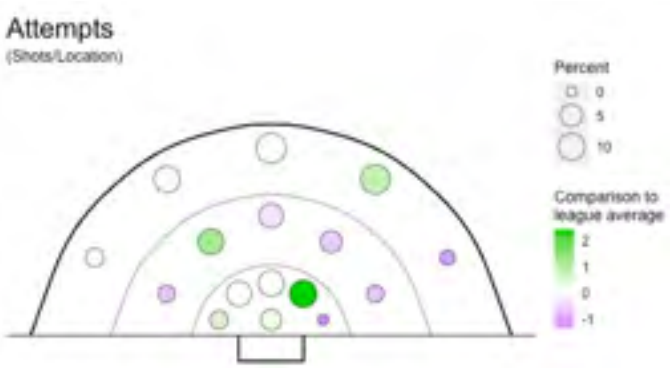


Figure 6.13 Goal shots heat map illustrating the percentage of goal shots from each of the 16 shooting locations for one team. The size of the circle indicates the percentage of shots from that location, with increasing size indicating a greater percentage of shots. Colour indicates comparison to the league average, purple indicating below average and green above average performance. For example, this team has approximately 10% of shots from the middle inner right zone (from the perspective of the shooter looking at the goals) which is a greater percentage than the league average.

This web-app provides information on the holistic game plan, identifies team strengths and differences, and the technical-tactical indicators that a strategy is built on. Future research should assess the ecological validity of the app by surveying analysts, coaches, and players in practice. This information would highlight the features that were insightful, what wasn't useful and what other ideas coaches would like to see developed. This approach will allow continual improvement of the performance analysis process, so it has the greatest impact on improving performance in practice.

6.6 Conclusion

We have outlined a practical approach to performance analysis in team invasion sports by identifying the key steps when capturing, analysing, visualising, and communicating data to gain insight into a team's strategy. Completing each step with a practical focus yields important insights that can directly inform a team's strategy. An example was provided analysing strategy in field hockey, and illustrated the key themes captured, methods of data analysis to extract layers of effective insights, and development of an interactive application for easy access and communication of visualisations. This performance analysis process can

be applied to any team invasion sport providing practical insights for coaches to develop and communicate specific strategies for different match situations.

6.7 Hyperlinks to R Code and Output

Data analysis R code - https://github.com/felicitylord/Hockey-Analysis

Game Styles Instructions and Output - https://rpubs.com/felicitylord/game-styles

Ball Movements Instructions and Output - https://rpubs.com/felicitylord/ball-movements

In-Game Events Instructions and Output - https://rpubs.com/felicitylord/in-game-events

Shiny App R code - https://github.com/felicitylord/Hockey-Analysis

Shiny App - https://felicity4.shinyapps.io/Hockey101/

6.8 References

1. Lord F, Pyne DB, Welvaert M, Mara JK. Methods of performance analysis in team invasion sports: a systematic review. J Sports Sci. 2020;38:2338-49.
2. Wright C, Atkins S, Jones B, Todd J. The role of performance analysts within the coaching process: performance analysts survey 'The role of performance analysts in elite football club settings'. Int J Perform Anal Sport. 2013;13:240-61.
3. Ribeiro J, Davids K, Araújo D, Silva P, Ramos J, Lopes R et al. The role of hypernetworks as a multilevel methodology for modelling and understanding dynamics of team sports performance. Sports Med. 2019;49:1337-44.
4. Ribeiro J, Silva P, Duarte R, Davids K, Garganta J. Team sports performance analysed through the lens of social network theory: implications for research and practice. Sports Med. 2017;47:1689-96.
5. Soltanzadeh S, Mooney M. Systems thinking and team performance analysis. Int Sport Coach J. 2016;3:184-91.
6. Travassos B, Davids K, Araujo D, Pedro Esteves T. Performance analysis in team sports: advances from an ecological dynamics approach. Int J Perform Anal Sport. 2013;13:83-95.
7. Salmon PM, McLean S. Complexity in the beautiful game: implications for football research and practice. Sci Med Footb. 2020;4:162-7.
8. Barris S, Button C. A review of vision-based motion analysis in sport. Sports Med. 2008;38:1025-43.
9. Ortega-Toro E, Garcia-Angulo A, Gimenez-Egido JM, Garcia-Angulo FJ, Palao JM. Design, validation, and reliability of an observation instrument for technical and tactical actions of the offense phase in soccer. Front Psychol. 2019;10:22.
10. Villarejo D, Ortega E, Gomez M-A, Palao J-M. Design, validation, and reliability of an observational instrument for ball possessions in rugby union. Int J Perform Anal Sport. 2014;14:955-67.
11. Gollan S, Ferrar K, Norton K. Characterising game styles in the English Premier League using the "moments of play" framework. Int J Perform Anal Sport. 2018;18:998-1009.
12. Fernandez-Navarro J, Fradua L, Zubillaga A, Ford PR, McRobert AP. Attacking and defensive styles of play in soccer: analysis of Spanish and English elite teams. J Sports Sci. 2016;34:2195-204.
13. Lago-Penas C, Gomez-Ruano M, Yang G. Styles of play in professional soccer: an approach of the Chinese Soccer Super League. Int J Perform Anal Sport. 2017;17:1073-84.

14. Losada AG, Theron R, Benito A. BKViz: a basketball visual analysis tool. IEEE Comput Graph Appl. 2016;36:58-68.
15. Perin C, Vuillemot R, Fekete J-D. SoccerStories: a kick-off for visual soccer analysis. IEEE Trans Vis Comput Graph. 2013;19:2506-15.
16. Polk T, Yang J, Hu Y, Zhao Y. Tennivis: visualization for tennis match analysis. IEEE Trans Vis Comput Graph. 2014;20:2339-48.
17. O'Donoghue P. Reliability issues in performance analysis. Int J Perform Anal Sport. 2007;7:35-48.
18. Hughes MD, Bartlett RM. The use of performance indicators in performance analysis. J Sports Sci. 2002;20:739-54.
19. Hewitt A, Greenham G, Norton K. Game style in soccer: what is it and can we quantify it? Int J Perform Anal Sport. 2016;16:355-72.
20. Greenham G, Hewitt A, Norton K. A pilot study to measure game style within Australian football. Int J Perform Anal Sport. 2017;17:576-85.
21. Castellano J, Pic M. Identification and preference of game styles in LaLiga associated with match outcomes. Int J Environ Res Public Health. 2019;16:5090.
22. Kale A, Nguyen F, Kay M, Hullman J. Hypothetical outcome plots help untrained observers judge trends in ambiguous data. IEEE Trans Vis Comput Graph. 2018;25:892-902.
23. Midway SR. Principles of effective data visualization. Patterns. 2020;1:100141.
24. Cawthon N, Moere AV. The effect of aesthetic on the usability of data visualization. 2007 11th International Conference Information Visualization (IV'07). 2007 4-6 Jul; Zurich, Switzerland, p. 637-48.
25. Weissgerber TL, Winham SJ, Heinzen EP, Milin-Lazovic J, Garcia-Valencia O, Bukumiric Z et al. Reveal, don't conceal: transforming data visualization to improve transparency. Circulation. 2019;140:1506-18.
26. Evergreen S, Metzner C. Design principles for data visualization in evaluation. In: Azzam T, Evergreen S, editors. Data Visulization part 2. New Directions for Evaluation; 2013. p. 5-20.
27. Joyce SC. Web based data visualisation applied to creative decision making in parametric structural design. Proceedings of IASS Annual Symposia; 2015; International Association for Shell and Spatial Structures (IASS). p. 1-12.
28. Yi JS, ah Kang Y, Stasko J, Jacko JA. Toward a deeper understanding of the role of interaction in information visualization. IEEE Trans Vis Comput Graph. 2007;13:1224-31.

29. Altman DG. Practical Statistics for Medical Research. London: Chapman & Hall; 1991. p. 404.
30. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2020.
31. Hennig C. fpc: Flexible Procedures for Clustering. R package version 2.2-9. 2020.
32. Chang W, Cheng J, Allaire JJ, Sievert C, Schloerke B, Xie Y, Allen J, McPherson J, Dipert A, Borges B. shiny: Web Application Framework for R. R package version 1.6.0. 2021.
33. Wickham H. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016.

Chapter 7 - Translating Data into Strategy

This chapter provides an example that illustrates how to translate data into strategy demonstrating the practical application of this research. The layers of data are analysed to describe a team's attacking style of play and how to develop a defensive strategy as an opposition coach. The strategy of the Argentina women's team to create goal scoring opportunities in established attack while drawing during a match is assessed.

As depicted in Argentina's game style profile in Figure 7.1, in the majority of games Argentina are strong and prefer dribbling in established attack, and play a possession tempo. Based on the interaction of these variables, the holistic game plan indicates Argentina are a high-pressure attacking team who like to engage the opposition. Analysing the components within the established attack success category (Figure 7.2) it can be identified that Argentina are strong as they are awarded a high number of set pieces, and have greater time and stoppages in the circle (AC) and attacking 25 (A25). However, they create fewer goal shots per game than average, and have less time and stoppages in the attacking 50 (A50) which is associated with the poor game style type. This is likely in part related to having a low ratio of slow to fast restart speeds in the A50 which indicates they more often play on quickly from a stoppage before the defence is reset providing them the opportunity to gain ground. Compared to other teams that are strong in established attack and play a possession tempo utilising the length and width of the attacking half, Argentina move the ball to the A25 quickly and maintain possession here so they can continually attempt to create circle entries and attack the goal. This pattern highlights how Argentina are different from teams with similar game style types and identifies a potential weakness an opposition can exploit.

Figure 7.1 Argentina women game style profile when drawing, illustrating percentage of games per game style type.

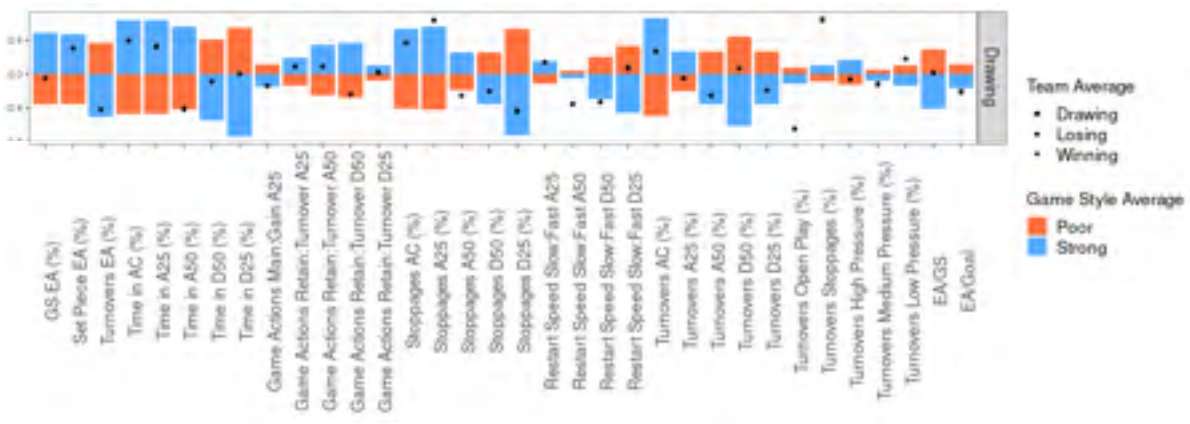


Figure 7.2 Argentina women Established Attack Success game style category when drawing illustrating variables on the x per z-score on the y, with bars indicating game style average for comparison. GS = Goal Shot, EA = Established Attack, AC = Attacking Circle, A25 = Attacking 25, A50 = Attacking 50, D50 = Defensive 50, D25 = Defensive 25.

Assessing the components of the established attack game actions category (Figure 7.3) illustrates how Argentina attack the circle. Although they were classed as a dribbling team based on this analysis, in the defensive half Argentina are more likely to pass the ball. It is only in the attacking half when they switch tactics to dribbling and tend to use crosses. This indicates Argentina attempt to create attacking opportunities by dribbling at and around defenders to create space to attack into, or will send a cross into the circle looking for a deflection. This profile details how they maintain possession in the A25, where Argentina looks to engage the defence by dribbling to create a space to attack into. If a defender cannot be beaten, a stoppage can be won by forcing a mistake out of the defender. Similarly, crossing the ball into the circle can lead to deflections at goal or a miss trap by a defender which can result in a stoppage. Creating stoppages in the attacking end allows Argentina to maintain pressure on the opposition in dangerous positions. This pattern provides another factor to target for an opposition coach.

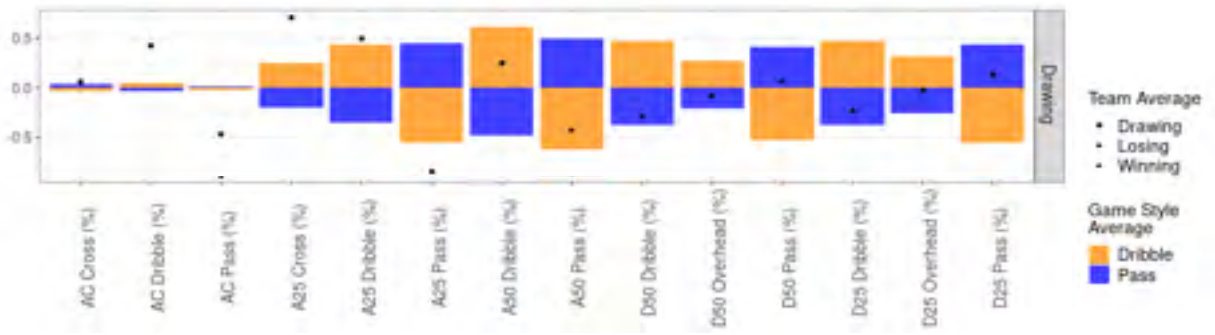


Figure 7.3 Argentina women Established Attack Game Actions game style category when drawing illustrating variables on the x per z-score on the y, with bars indicating game style average for comparison. AC = Attacking Circle, A25 = Attacking 25, A50 = Attacking 50, D50 = Defensive 50, D25 = Defensive 25.

The next step of the analytic process is to interpret Argentina's ball movement profile (Figure 7.4) to examine more closely where they move the ball in relation to how they attack. When Argentina were drawing, they had greater game possession and possession in the circle than most teams. This concurs with the interpretation from our game style profile that they can control the ball in attacking positions. Although Argentina tends towards greater possession in the attacking half, there are no extreme values for possession or entropy per zone. Therefore, the direction of ball movement will explain how they ended up with this profile. Focusing on the zones in the attacking half, it appears that Argentina are more likely than other teams to move the ball forward from build attack to the corners, travel back from deep attack to build attack, and straight into the circle from the corners. These points indicate that Argentina have the skills and ability to maintain possession, and do not need to go directly at goal, hence why they are classed as a possession team. This analysis also indicates that the corners are the key zone to create circle entries for Argentina as they want to attack from here rather than just maintain possession. This illustrates to an opposition coach that this is an area that needs protecting.

Figure 7.4 Argentina women ball movement profile when drawing illustrating variables on the x and attack zones on the y, with colour indicating z-score for comparison to the league average.

Looking more closely at the specific areas on the field using a heat map, as seen in Figure 7.5 which illustrates possession per cell, Argentina have greater movements along the edges of the field, and fewer movements in the central channels. This illustrates that possession in the build attack zone is greater down the sidelines than transferring the ball side to side along the halfway line. This information suggests Argentina prefer moving the ball down the sidelines towards the corner, rather than through the centre, before shifting the ball into the circle. The opposition defence is more likely to guard the centre channels of the field as movement through these channels provides a better angle at goal to create goal shots, and consequently there is greater space out wide. Argentina are able to take advantage of this and move quickly into the A25. This reflects what was observed in the analysis of the established attack success category. However, by identifying that possession in the A25 is in a less dangerous position

in the outer channels and corners reduces the perception of the attacking threat of Argentina. It also reflects why they create fewer goal shots, and greater set pieces, as it is easier for a defence to set up to prevent the attack getting to a good angle for a goal shot. However, Argentina are able to still create positive outcomes from this strategy by winning penalty corners when their path to goal is blocked. The reduced attacking threat of Argentina is also highlighted by assessing goals for and against per match (Figure 7.6), which indicates in majority of matches Argentina are only scoring 1 or 2 goals. This detail informs an opposition coach that Argentina can be prevented from creating goal scoring opportunities by setting up an appropriate defensive structure.

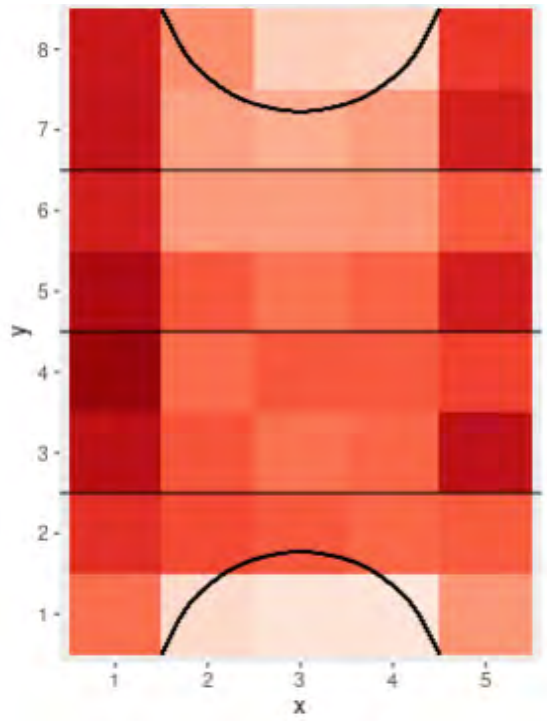


Figure 7.5 Argentina women heat map illustrating possession per cell, the darker the cell the higher the percentage. Team is attacking towards top of figure.

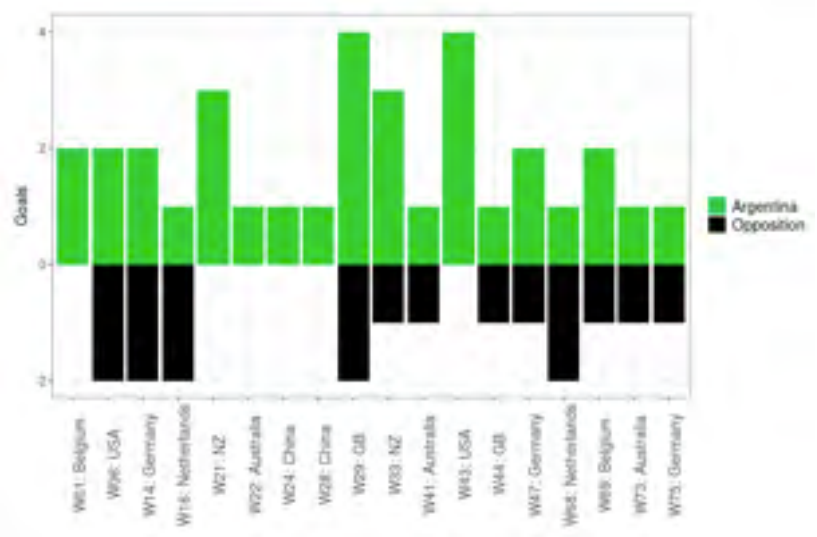


Figure 7.6 Argentina women goals for (green) and against (black) per match.

The spatial distribution and game actions used are reflected in the in-game events analysis, the third level of analysis providing key skills for developing a defensive strategy. Analysing Argentina's stoppage profile (Figure 7.7) shows that they have greater stoppages as long corners and sideline hits, which are stoppages due to the ball being played out of bounds. Playing down the edge of the field provides the opportunity to win stoppages as the opposition defence may be more likely to knock the ball out of play, rather than take clean possession, when attempting to tackle or intercept the ball. However, these strengths can become weaknesses if the opposition's defence is structured correctly. Studying Argentina's turnover profile (Figure 7.8), it is evident they have higher turnovers due to the ball being played out of bounds in the circle and A25, and they are also more likely to be tackled in the circle.

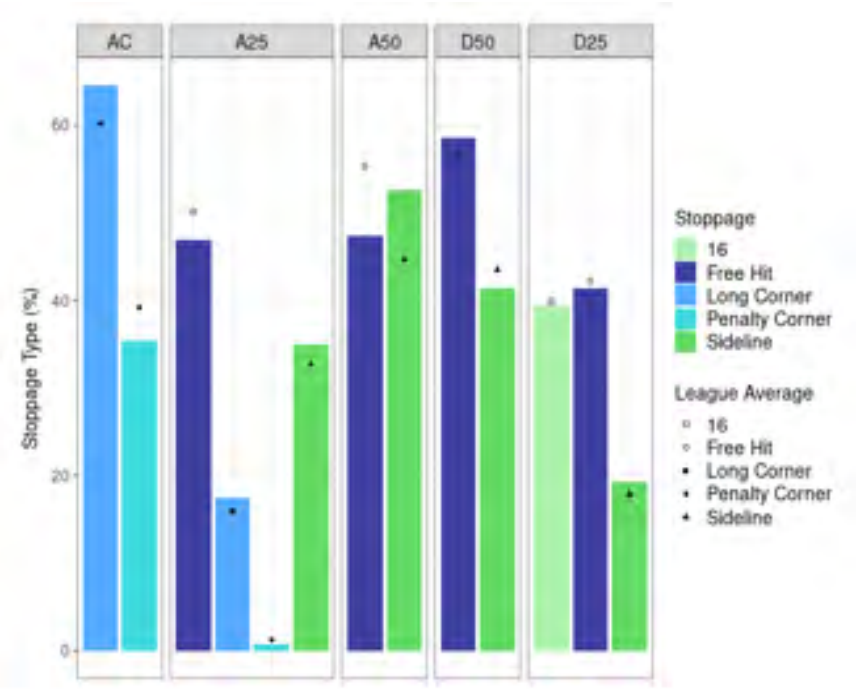


Figure 7.7 Argentina women stoppage types per location. Bars indicate team average and dots league average.

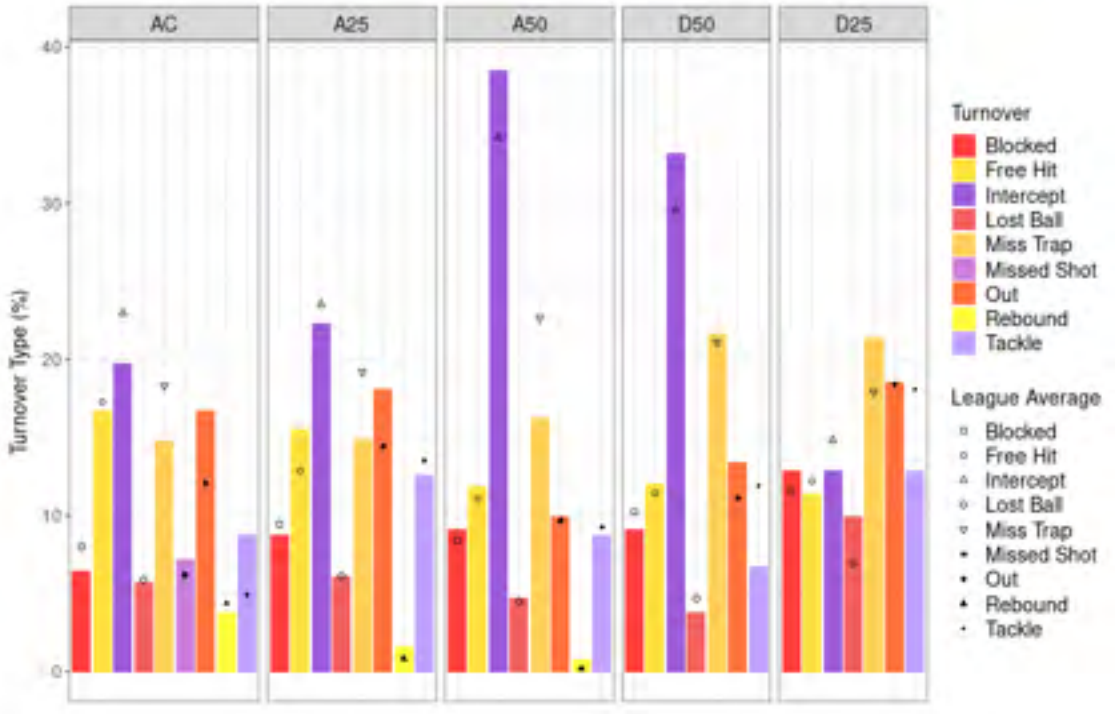


Figure 7.8 Argentina women turnover types per location. Bars indicate team average and dots indicate league average.

Together, these layers of analysis illustrate Argentina's strategy of utilising the edges of the field to move quickly through space to the corners, and then attack the circle by dribbling or crossing the ball. As an opposition coach, a defensive strategy can be based on restricting Argentina's attacking space and limiting engagement with their attackers to force them to find an alternative method of maintaining possession and attacking the goal. The first stage of the defensive strategy involves setting up a zone with high numbers on the side of the ball in the A50 to attempt to force Argentina to maintain possession in this area without moving forward quickly (Figure 7.9A). The players on the side of the ball will be responsible for the closest Argentina player to limit easy passes between attackers, the highest central striker is placed in front of the ball, the free defender at the back of the pack, and other side defenders slide across to help (Figure 7.9B). This pattern creates high numbers in front of the ball, congesting the space and creating a 2v1 if Argentina attempt to move through this zone to the A25. Space and unmarked players are available on the other side of the field, as well as the pass to transfer the ball to the other side (Figure 7.9C). This provides them with the opportunity to switch sides and attack the space. However, if Argentina switch sides then the defence follow, guarding the space and not attempting to engage the attackers (Figure 7.9D).

The handoff of players marking allows the space and attackers to be covered as the zone has now set up on the other side of the field (Figure 7.9E). This means the free space is once again away from the ball, there is no easy or direct route to A25, and more opportunities are created to force a turnover (Figure 7.9F). If Argentina continue to move the ball down the sideline, there is limited space to do so and they can be forced out of bounds. If they attempt to move the ball through the centre of the field, then the defenders outnumber the attackers and can look to cause turnovers by tackling. Finally, if Argentina simply aim to maintain possession by transferring the ball from side to side the value of this possession is reduced.

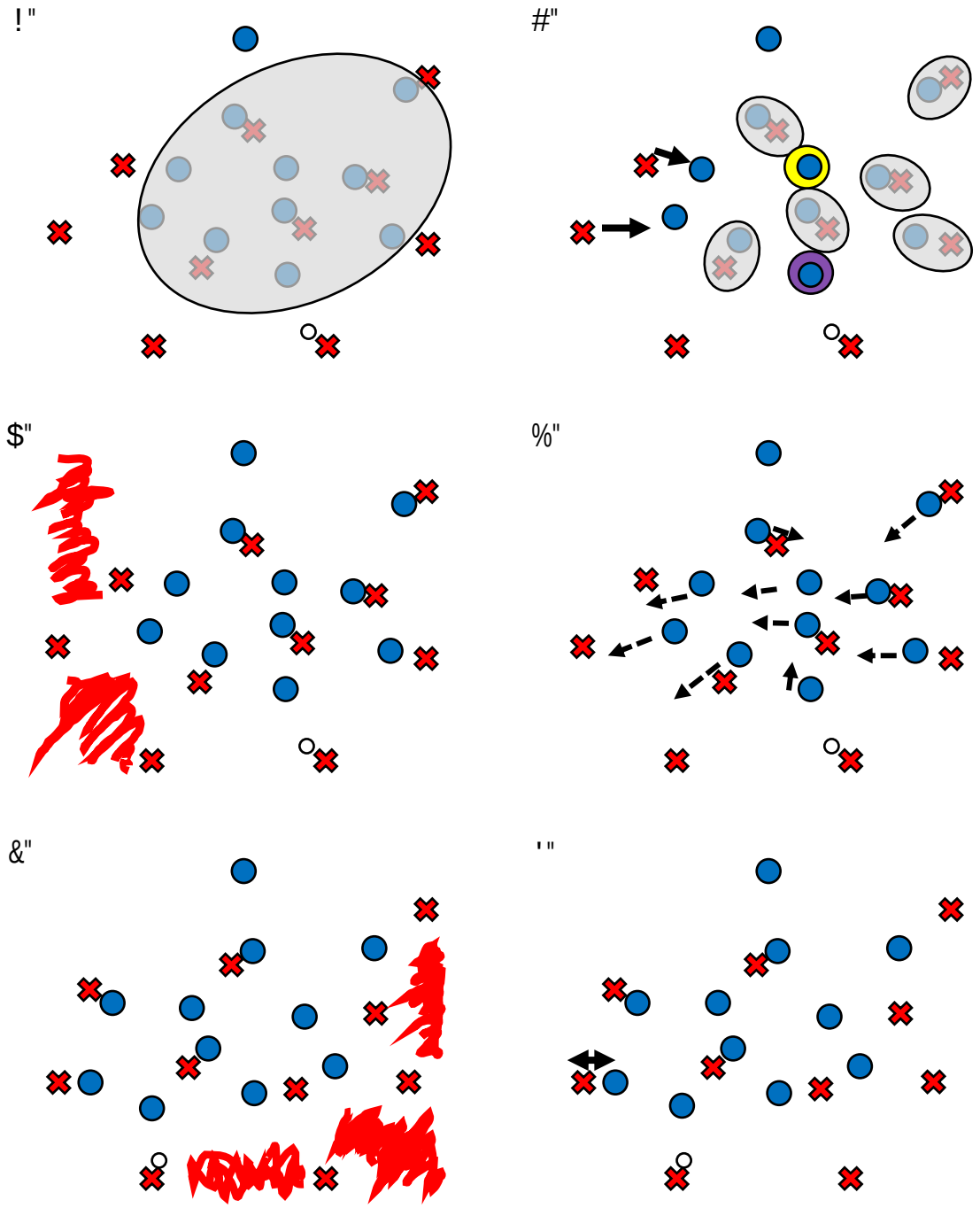


Figure 7.9 Defensive strategy part 1, Argentina are represented by ✖ and the opposition by ●. **A** Defensive zone **B** Player roles **C** Space on other side **D** Switch sides **E** Zone and space relocated **F** Turnover options.

If Argentina are able to move the ball to and maintain possession in the A25, then the second stage of the strategy is preventing circle entries by setting up a similar defensive zone (Figure 7.10A). Goals can only be scored from a goal shot within the circle in field hockey, therefore having high numbers around the circle restricts the ability of a team to be attacking. Given that Argentina like to dribble or cross the ball into the circle from the corners, the zone will focus on protecting space along the baseline. Defenders in the circle will be responsible for the closest attacking player so there are no free attackers in this area (Figure 7.10B). The free central defender and wide striker will move back to block up the corner and baseline. However, the defence will not engage the Argentinian striker attempting to dribble through them. Holding a set line on the edge of the circle restricts the attacking space for the striker to move into, and it becomes more difficult to move forward. Argentina will use dribbling to attempt to draw out defenders to create a hole to attack into. By holding a set line, the only space offered is backwards away from goal to the A50 if Argentina do not want to risk giving up possession of the ball (Figure 7.10C).

Argentina will attempt to spread the defence by moving the ball backwards, but by maintaining the defensive zone around the circle the only option provided to move forward is to switch sides to the opposite corner. If Argentina switch sides, then the defence follows (Figure 7.10D). This defensive strategy is testing the patience of Argentina to maintain possession without attacking the circle (Figure 7.10E). By the defence not engaging the attack or actively looking for turnovers, Argentina is forced to make a decision to take on the zone defence or attempt a riskier plan (Figure 7.10F). This provides opportunities for turnovers if Argentina attempt to dribble through the defence; they could get tackled as they are out-numbered, or they could be forced out of bounds by trying to go around the defence. Argentina may attempt a riskier option through the centre of the field where the attackers and midfielders are set up waiting to counter attack from a turnover. Alternatively, if Argentina bring up more attackers to create an equal number of attackers and defenders in the circle, it will create further congestion of the space and increase the difficulty of moving the ball through effectively.

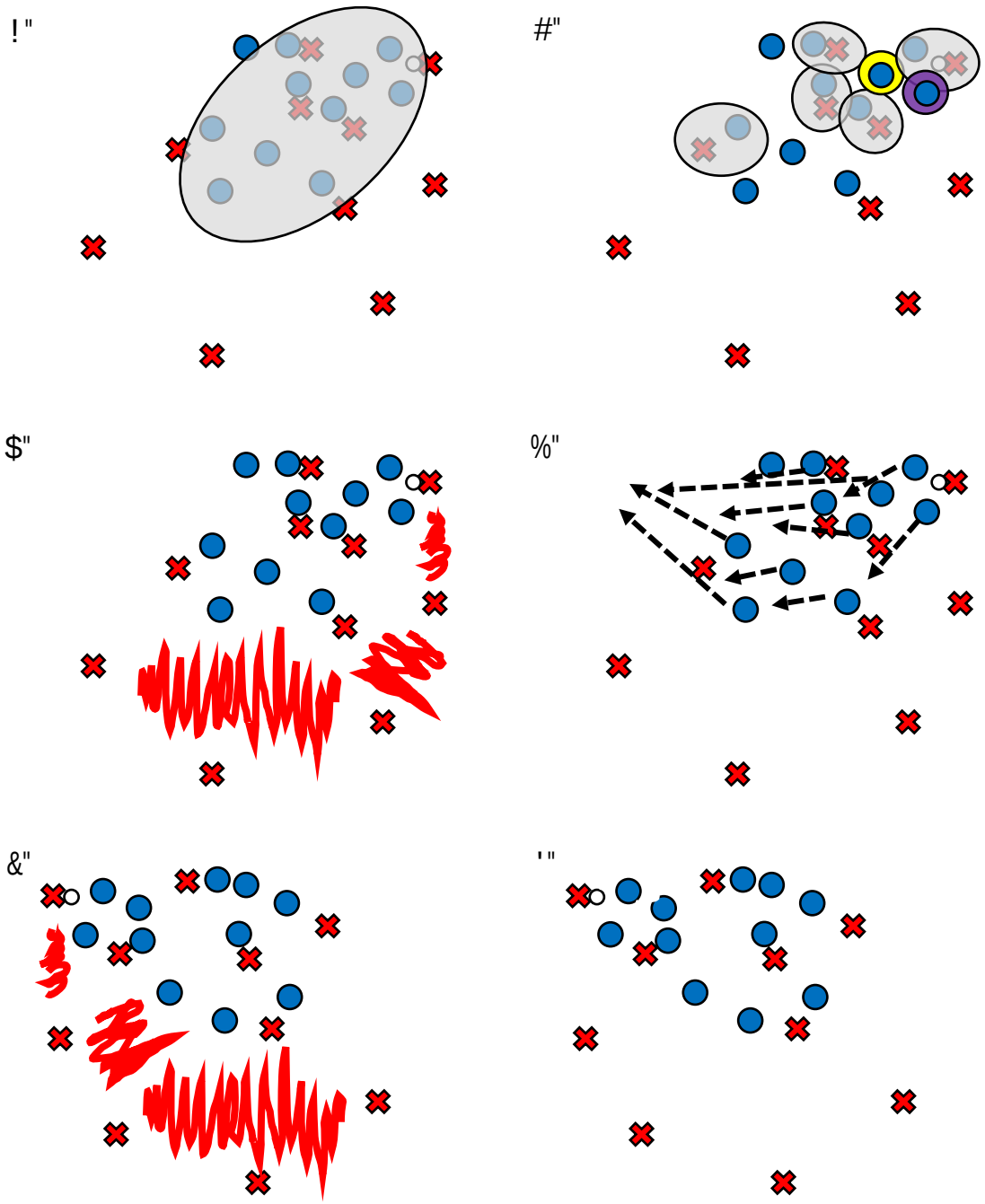


Figure 7.10 Defensive strategy part 2, Argentina are represented by ✖ and the opposition by ●. **A** Defensive zone **B** Player roles **C** Space in A50 **D** Switch sides **E** Zone and space relocated **F** Turnover options.

Chapter 8 - Discussion

8.1 General Discussion

Strategy in team invasion sports is both simple and complex in nature. It is simple due to the common goal of outscoring an opponent, but complex given the individuality of *how* teams create goal scoring opportunities. Performance analysis, the act of objectively measuring strategy, must also provide simple and complex perspectives to quantify what a team is trying to do, and how they go about achieving it so a coach can understand why they are successful. I developed an evidence-based practical performance analysis process in field hockey that outlines how to capture, analyse, visualise and communicate layers of strategical information. The process highlights the importance of analysing game events in relation to time, space and the opposition, and analysing individual team strategy given the minimal influence of match context. There are several ways to win a game, so the performance analysis process must be able to consider all strategies a coach has implemented and those yet to be utilised in practice.

This thesis is comprised of several chapters that describe the rationale behind the performance analysis process chosen and the implementation of this process in practice. Chapter 2 comprised a systematic review on traditional and contemporary performance analysis techniques in team invasion sports to identify current best methods. Chapter 3 presented a systematic review on performance analysis techniques and considerations specific to field hockey. Chapters 4 and 5 were experimental studies that quantified game styles and ball movement patterns in international field hockey teams, respectively. The data capture and analytic techniques used in these studies formed the basis of Chapter 6. This chapter outlined the performance analysis process to develop a web-based application for presenting visualisations showing the link between the simple and complex concepts of strategy.

A review of the literature on performance analysis techniques in all team invasion sports and field hockey identified three main points. First, team invasion sports are dynamic, complex systems so performance must be recorded in relation to time, space, and opposition to account for this environment (Ribeiro et al., 2019; Ribeiro et al., 2017; Soltanzadeh and Mooney, 2016; Travassos et al., 2013). This approach allows an analyst to relate processes to outcomes to understand how a team is successful. Secondly, strategy can be measured from different systematic levels of performance (i.e., game, team and player), however these levels must be considered as a cyclic relationship as each level will have an effect on another

(Araujo et al., 2015; Grehaigne et al., 1999). The actions of one player will result in a change in a team structure, eliciting a positive or negative event in the game. Thirdly, performance analysis techniques in research are only as useful as their practicality in the real world. In practice, the techniques chosen by analysts are limited by the resources available, time constraints between games, and data analysis skills of the analyst. These three points formed the basis for developing a performance analysis process for use in field hockey in practice.

Chapter 2 identified three effective techniques to analyse team invasion sports as a dynamic complex system; analysing in-game events through game styles analysis (Fernandez-Navarro et al., 2016; Gollan et al., 2018; Greenham et al., 2017), analysing team structures through collective team behaviours (Alexander et al., 2019; Clemente et al., 2013), and analysing intra-team dynamics through social network analysis (Clemente et al., 2014; McLean et al., 2018). Each technique analyses performance from a different systematic level. However, as outlined in Chapter 3, the feasibility of gathering data for collective team behaviours and social network analysis in field hockey is limited due to the time and resources available. Equipment is generally restricted to a video camera and notational analysis system that focuses on recording data from a game perspective. Consequently, game styles analysis was selected as the most appropriate method of performance analysis in field hockey, and the concept was explored in two experimental studies.

A game style is defined as the consistent strategy implemented by one team (Hewitt et al., 2016). Game styles are developed by reducing large sets of detailed variables into key factors by assessing the interaction of common variables or observations. These factors highlight common patterns in the data that relate and reflect how outcomes occurred which an analyst would have had to otherwise identify manually. It is the skill of the analyst to interpret these factors, and communicate the process behind the strategy based on their experience and domain knowledge. These skills are an essential part of the performance analysis process to explain the cause and effect relationship between variables from a holistic perspective. For example, as discussed in Chapter 4, set piece occurrence and established attack success were most important in determining the game style in the other category due to their common thread of maintaining possession in attacking positions. Previous research has focused on game styles from a game perspective by identifying styles based on game actions, attack types and tempos (Castellano and Pic, 2019; Fernandez-Navarro et al., 2016; Gollan et al., 2018; Gomez et al., 2018; Greenham et al., 2017; Lago-Penas et al., 2017). However, the process of creating a game style was reimagined in this thesis to consider performance not

only from a game perspective, but also to account for team and player roles. Two experimental studies were conducted to provide differing yet complementary insights into the consistent strategy of international field hockey teams.

Analysing in-game events, as detailed in Chapter 4, identifies what a team does with the ball by calculating the likelihood of actions and outcomes occurring. This method considers the game level of performance derived from measuring each event in relation to the interaction with the opposition. This information reflects the basis of team invasion sports of simultaneously attempting to score and prevent the opposition scoring goals. This process echoes the method used in previous research; however, it additionally considers all components that can manipulate strategy to provide a more holistic understanding of performance. Analysing ball movement patterns (Chapter 5) identifies how and where a team moves around the field placing greater focus on time and space and allows performance to be considered from a team and player level. Heat maps illustrating possession identify where a team moves the ball giving insight into the way a team is structured. Entropy and progression rates indicate how the ball is moved highlighting the zones, and therefore players (or positions based on the location on the field) that are connected. In field hockey, there is no limit on the number of substitutions that can occur within a game meaning there is a constant rotation of players through positions. Players will fill a role in the team strategy so analysing the connections between positions, as opposed to individual players, may be more informative. An alternate approach to analysing team structure and player networks with basic equipment and developing game styles from ball tracking data is provided. Both methods described in this thesis capture strategy as a dynamic complex system. However, game style profiles consider how a team interacts with the opposition to create outcomes, while ball movement profiles consider how the players in a team interact.

The limited influence of match context on strategy reinforces the need to analyse individual team strategy. The results of the decision trees in Chapter 4 identified that the oppositions' game style and other components of the reference team's game style had the greatest effect on performance. This outcome highlights that a team's overall strategy is determined by the interaction of all components of performance, and the importance of developing a strategy that accounts for the oppositions' strengths and weaknesses. The strength of the opposition will determine the starting position of a team's attack, whether in the defensive or attacking half, and consequently the pressure they face to control and maintain possession of the ball. Thus, it is the opposition that has the major influence on the game actions and tempo a team

chooses to use based on the decision to attack, maintain possession, or protect their goal. The game style profile produced details how a team attempts to be successful considering the influence of their interaction with the opposition. Similarly, play outcomes were able to distinguish movement patterns in Chapter 5. However, the favourable conditions needed to create goal scoring opportunities are minimal in field hockey highlighting the importance of identifying how a team creates this situation. Success was associated with a team's ability to move the ball quickly to, and maintain possession, in the attacking half. This highlights the need to identify strategies occurring in different phases of play to understand the attacking ability and intent of a team to generate a sequence of plays ending in a goal scoring opportunity in different moments of the game. A ball movement profile can analyse a team's strategy in different phases of play by considering how the players and team collectively move the ball around the field.

A major consideration in selecting a performance analysis technique is the ability to communicate practical insights from both a simple and complex perspective and the layers that connect them. Game styles analysis was selected given the inherent reduction process that translates information from simple, detailed events to complex, holistic components making it interpretable in practice. Previous research has focused on the output of this process to describe the holistic strategy in team invasion sport. However, there has been a missed opportunity to appreciate this translation process to provide a more comprehensive look at the building blocks of a strategy. Data visualisation techniques were employed in this thesis to complement this process, illustrate the links or translation between data capture and analysis, and highlight how both forms of data are necessary to gain the most effective insight into strategy. The web-based application was developed as an effective tool to visualise and communicate a sequence of images that translates data into strategy. Each layer of analysis allows an analyst to understand, develop and communicate strategy based on the level of detail needed. The game styles analysis process presented in this thesis included an extra step in the reduction method by including predetermined categories of performance for in-game events, and attacking zones for ball movements. This inclusion allowed a more gradual progression from specific detailed events to generalised events, and the main components of play and finally holistic profiles. This approach facilitates easier interpretation of the data and connection between ideas.

The game styles analysis process presented has allowed the language used in practice to be quantified and provided objectivity to coach observations. Analysing the interaction between

game style categories or ball movement variables yields common strategies that reflect how teams are discussed in practice. For example, the interaction of established attack success and tempo identifies a team's intent to attack, and established attack game actions and tempo illustrates how they intend to attack. Alternatively, the interaction of entropy and progression rates indicates the range and direction a team can control the ball, or possession and progression rates indicate the length of possession and the number of opportunities within a zone. Table 8.1 and 8.2 describe examples of interpreting common strategies in field hockey based on the interaction of game style categories and ball movement variables respectively.

Table 8.1 Common strategies in field hockey identified from the interaction of game style categories

Game Style Category 1		Game Style Category 2		Strategy	Interpretation
Established Attack	Strong	Tempo	Possession	High pressure attack	Maintain possession in attacking positions, move the defence around until a good opportunity to attack arises
	Strong		Direct	High intensity attack	Continually look to move forward and attack the circle at high speed
	Poor		Possession	Maintenance	Prevent the opposition getting the ball
	Poor		Direct	Protection	Remain in defensive positions, remove ball from danger areas rather than try to control possession
Established Attack Game Actions	Dribble	Tempo	Possession	Contests	Engage with opposition to win stoppages
	Dribble		Direct	Running space	Attack space with individual skill and speed
	Pass		Possession	Maintain	Short passes away from the opposition
	Pass		Direct	Passing space	Long passes into space to eliminate defenders
Established Attack Success	Strong	Established Defence Success	Strong	One sided attack	High attacking opportunities for and low against
	Strong		Poor	End to end game	High attacking opportunities for and against
	Poor		Strong	Middle contest	Low attacking opportunities for and against
	Poor		Poor	One sided defence	Low attacking opportunities for and high against
Established Attack Success	Strong	Counter Attack Success	Strong	All round attack	Create attacking opportunities under any situation
	Strong		Poor	Structured attack	Create attacking opportunities when attack is planned and builds slowly
	Poor		Strong	Unstructured attack	Create attacking opportunities when defence are unbalanced
	Poor		Poor	Poor attack	Struggle to create attacking opportunities when opposition are balanced or unbalanced

Table 8.2 Common strategies in field hockey identified from analysing the interaction of ball movement variables in build attack

Ball Movement Variable 1		Ball Movement Variable 2		Strategy	Interpretation
Entropy	Predictable	Progression Rates	One - Stay	Maintain position	Transfer ball in same path within zone
	Unpredictable		One - Stay	Maintain possession	Utilise length and width of zone to keep ball away from the opposition
	Predictable		One - Forward	Attack direct	Utilise same path to attack
	Unpredictable		One - Forward	Attack space	Look to go forward but through different paths
	Unpredictable		Multi	Maintain pressure	Utilise length and width of field to maintain possession in attacking positions
Possession	High	Progression Rates	One - Forward	High intensity attack	Short possessions, high opportunities in zone
	High		One - Stay	Maintain	Long possessions, low opportunities in zone
	Low		One - Forward	Direct	Short possessions, low opportunities in zone
	Low		One - Stay	Slow attack	Long possessions, low opportunities in zone
	High		Multi	High pressure attack	Short possessions, high opportunities in zone

8.2 Practical Applications

The primary aim of this thesis was to develop an evidence-based practical performance analysis process that provides practical insight into strategy by capturing, analysing, visualising, and communicating layers of simple and complex information. This approach is highlighted in Chapter 7 by presenting an example of translating data into an attacking and defensive strategy. The importance of analysing the interaction of game events in relation to spatio-temporal measures and player-opposition interactions is highlighted. Additionally, the benefit of presenting layers of complex information in simplified formats is outlined to gain the greatest understanding into how each team is successful. The development of the web-based application illustrates how to present this data in an accessible, informative and interpretable format in practice.

While technology has advanced leading to the development of new performance analysis methods, we have shown that quality information can still be delivered using basic equipment of a notational analysis system and video camera. This method is more applicable for lower funded sports and competition levels to ensure there are no restrictions on improving future performance for these athletes and teams.

The basis of the process stems from understanding the key components of strategy and how they can be manipulated. This approach can be adapted to similar team invasion sports such as soccer or Australian Football to generate similar insights into specific team strategy. An analyst just needs to identify the relevant attack types, game actions, tempos and phases of play within their sport.

The novel approaches to quantifying game styles provide options for assessing strategy. Game styles developed from in-game events provides greater focus on opposition interactions, however, the manual data collection can be time consuming due to the number of variables captured. Game styles developed from ball movements provides greater focus on spatio-temporal measures and takes less time to code as fewer components are captured. An analyst with limited time can choose one method better suited to their predetermined question and gain valuable insight. However, utilising both methods provides a more comprehensive insight into strategy.

The performance analysis process outlined can be used to prepare for upcoming games or tournaments, as video footage is reviewed retrospectively to capture detail reliably and

accurately. However, the insights gained can be used to decide which variables are important to capture and assess in real time during a game. On this basis, an analyst can adapt the way data are captured during a game to reflect game styles, as opposed to general match outcomes. For example, recording possession percentage is important for teams attempting to play a possession game style but less so for teams playing a direct game style.

Identifying an opposition's technical-tactical strengths and weaknesses allows more targeted training drills to be completed in preparation for a game, and selection of players with the skills to counteract the opposition. For example, selecting defenders with high tackling ability for opposition that prefer dribbling in attack, compared to defenders able to read the play and create intercepts for opposition teams that use long passes into space.

8.3 Limitations

A limitation of completing retrospective analysis, as was employed in this study, is that analysis is restricted to the quality of video footage captured. As video footage was provided from external sources, there was no way of ensuring quality of the video. As such, some footage was captured from poor angles and distances which limited the ability to accurately record key events. Similarly, footage from TV coverage also included replays within the game which obscured passages of possession. However, these limitations had a minimal affect given the inclusion of multiple camera angles from a team analyst, and TV coverage allowing passages of play to be cross referenced.

Not all games from the tournament were able to be analysed as video footage was not provided for those games. As it was an international tournament played across different countries, as opposed to one location, teams relied on the sharing of captured video footage for analysis. It is unknown whether the missing matches were not captured or shared. There were 2 games missing for the women and 3 games for the men. However, all teams had a minimum of 15 games for the women (maximum 18 games) and 11 games for the men (maximum 16 games) for the tournament.

Another aspect that may have limited the results was the range (standard) of teams included. As this was an international tournament played by the top ranked nations, the lack of difference between higher and lower ranked teams and match status may relate to the similar level of ability of players between teams. If another tournament with a wider range of teams was analysed, greater differences between teams' game styles may have been observed.

It was planned to capture and analyse data from two years of the field hockey tournament, however due to COVID-19 only a single tournament year was analysed. Capturing data from a second tournament year would have provided increased certainty of game styles used and allowed comparisons of strategies over time. Due to restrictions surrounding COVID-19, the second year of the tournament (2020) was postponed which ultimately limited the analysis to the 2019 tournament given the timeframe of the thesis.

The time-consuming nature of manual data collection restricted the number of games coded and is in itself a limitation of capturing highly detailed information in practice. It took approximately 4 hours to capture data for one game for in-game events and 2 hours for ball movement patterns. However, the emergence of technology that uses computer vision and

pattern recognition to semi-automatically capture this information will reduce the time spent on this task. This is an area that can be explored in further research to make the data capture process more efficient.

We decided to analyse both male and female field hockey teams for this thesis. Focusing on just one gender may have provided the opportunity to analyse additional games per team or conduct further analysis. However, both genders were included to provide a greater insight into the influencing factors in field hockey, as well as reflecting the growing interest in society to analyse both genders in parallel.

Although there was limited peer-reviewed performance analysis research identified, this does not necessarily mean that these contemporary techniques or others are not being used in practice. Practitioners can be hesitant to share their ideas or data to maintain a competitive advantage in elite competitions. This limited the ability of this thesis to analyse collective team behaviours from GPS monitoring as data could not be collected from other teams competing in the Pro League tournament.

8.4 Future Research Directions

Future research should look to increase the database of games by analysing other international field hockey tournaments. A greater sample size of games analysed for a team will increase the accuracy of information pertaining to their strategy, and permit specific team match ups to be analysed. However, data should only be analysed within a limited time period (such as a 4-year cycle between Olympics) given the turnover of players and coaching staff that would impact a team's strategy.

Junior international tournaments should also be analysed and compared to senior competitions to identify differences in team styles. This process can be used to prepare upcoming players and facilitate an easier transition into the senior system. Similarly, lower levels of competition could be assessed such as national competitions to understand if there are differences between higher and lower quality teams, and whether there are areas that need addressing to continue to develop international standard players.

The performance analysis process described in this thesis could also be adapted to quantify individual player styles. Data could be captured from an individual player, rather than a team perspective to identify the game events and outcomes they are involved in and how effective they are. This approach would identify player roles, as opposed to positions on the field, based on an overall team strategy. The effectiveness of different team line ups on a team strategy and success could be identified as well as the ability to easily identify players with similar skills if a replacement was needed.

As both methods of analysing game styles were shown to produce effective insight into strategy, future research could consider combining the code windows presented into one to reduce the time taken to capture data. The types of game actions, stoppages, turnovers and goal shots from the in-game events code window could be recorded per 40 cells in the ball movement profile code window. This approach may provide a more holistic insight into game events in relation to spatio-temporal variables and opposition interactions. This idea could be adapted to capture data live during a match as game styles should be assessed, not just general outcomes. A simplified code window could be produced to record the number, as opposed to types, of actions and outcomes per attacking zones. This development would provide the opportunity to assess their game style and identify if a team was executing their strategy.

Investigators should explore the application of pattern recognition techniques to semi-automatically capture data on strategy. Currently, analysts must find a balance between the amount of data captured and the time taken to capture it. Developing an affordable program to automate this process would allow a greater amount of time to be spent on analysing and communicating the results.

As team structure and player connections were also shown to be important areas to analyse, future research could adapt the notational analysis process to place greater emphasis on these components. For example, team structure could be captured by recording the number of players in different areas on the field to indicate the length, width and area covered by a team. Player connections are captured through identifying the individual players performing each game action and who they are passing to. However, for this analysis to occur it is important to have appropriate video footage. A zoomed-out view of the field is needed to analyse team structure while close up vision is needed for player analysis. The ability to have multiple camera angles during a match would provide greater ability to analyse strategy on different levels. Research should continue to assess how to make the best use of resources available to ensure effective insights into team sport strategy.

In practice, performance analysts do not only capture game-based performance metrics but also physical performance measures such as total distance covered or high-speed sprinting efforts. Future research should consider developing team and player profiles based on the combination of physical and game-based data as this provides a more comprehensive insight into the strategy and capabilities of players and teams.

8.5 Conclusion

I have redesigned the performance analysis process by presenting an evidence-based practical approach to capturing, analysing, visualising and communicating strategy in field hockey. Identifying a team's consistent strategy through game styles analysis was identified as the most appropriate performance analysis technique to implement in field hockey. However, game styles analysis was re-envisioned by presenting novel methods that captured and analysed both in-game events in relation to the opposition, and ball movement patterns in relation to time and space. Visualisation techniques were used to link the simple to complex layers of information and translate data into strategy. The methods used capture and analyse the dynamic, complex nature of field hockey from a game, team and player perspective using basic equipment reflective of performance analysis in field hockey. The project has provided a more practical approach to performance analysis through appreciating the individuality of teams, and the ability to gain insight into both the holistic game plan and specific processes used to develop strategy. This research should have an impact in practice as it captures the complexity of strategy and unravels it, presenting the critical information in simple real-world language.

8.6 References

1. Alexander JP, Spencer B, Mara JK and Robertson S. (2019) Collective team behaviour of Australian Rules football during phases of match play. *Journal of Sports Sciences* 37: 237-243.
2. Araújo D, Passos P, Esteves P, Duarte R, Lopes J, Hristovski R and Davids K. (2015) The micro-macro link in understanding sport tactical behaviours: integrating information and action at different levels of system analysis in sport. *Movement & Sport Sciences-Science & Motricité* 89: 53-63.
3. Castellano J and Pic M. (2019) Identification and preference of game styles in LaLiga associated with match outcomes. *International Journal of Environmental Research and Public Health* 16: 5090.
4. Clemente FM, Couceiro MS, Martins FML, Mendes R and Figueiredo AJ. (2013) Measuring collective behaviour in football teams: inspecting the impact of each half of the match on ball possession. *International Journal of Performance Analysis in Sport* 13: 678-689.
5. Clemente FM, Couceiro MS, Martins FML and Mendes RS. (2014) Using network metrics to investigate football team players' connections: a pilot study. *Motriz: Revista de Educação Física* 20: 262-271.
6. Fernandez-Navarro J, Fradua L, Zubillaga A, Ford PR and McRobert AP. (2016) Attacking and defensive styles of play in soccer: analysis of Spanish and English elite teams. *Journal of Sports Sciences* 34: 2195-2204.
7. Gollan S, Ferrar K and Norton K. (2018) Characterising game styles in the English Premier League using the “moments of play” framework. *International Journal of Performance Analysis in Sport* 18: 998-1009.
8. Greenham G, Hewitt A and Norton K. (2017) A pilot study to measure game style within Australian football. *International Journal of Performance Analysis in Sport* 17: 576-585.
9. Gréhaigne J-F, Godbout P and Bouthier D. (1999) The foundations of tactics and strategy in team sports. *Journal of Teaching in Physical Education* 18: 159-174.
10. Gómez M-Á, Mitrotasios M, Armatas V and Lago-Penas C. (2018) Analysis of playing styles according to team quality and match location in Greek professional soccer. *International Journal of Performance Analysis in Sport* 18: 986-997.
11. Hewitt A, Greenham G and Norton K. (2016) Game style in soccer: what is it and can we quantify it? *International Journal of Performance Analysis in Sport* 16: 355-372.

12. Lago-Penas C, Gomez-Ruano M and Yang G. (2017) Styles of play in professional soccer: an approach of the Chinese Soccer Super League. *International Journal of Performance Analysis in Sport* 17: 1073-1084.
13. McLean S, Salmon PM, Gorman AD, Stevens NJ and Solomon C. (2018) A social network analysis of the goal scoring passing networks of the 2016 European Football Championships. *Human Movement Science* 57: 400-408.
14. Ribeiro J, Davids K, Araújo D, Silva P, Ramos J, Lopes R and Garganta J. (2019) The role of hypernetworks as a multilevel methodology for modelling and understanding dynamics of team sports performance. *Sports Medicine* 49: 1337-1344.
15. Ribeiro J, Silva P, Duarte R, Davids K and Garganta J. (2017) Team sports performance analysed through the lens of social network theory: implications for research and practice. *Sports Medicine* 47: 1689-1696.
16. Soltanzadeh S and Mooney M. (2016) Systems thinking and team performance analysis. *International Sport Coaching Journal* 3: 184-191.
17. Travassos B, Davids K, Araujo D and Esteves PT. (2013) Performance analysis in team sports: advances from an ecological dynamics approach. *International Journal of Performance Analysis in Sport* 13: 83-95.