Translating novel collective behaviour measures to concepts and principles of play as understood by football coaches.

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Translating novel collective behavior measures to concepts and principles of play as understood by football coaches.

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Abstract

Background: A range of innovative performance analysis metrics have been applied in recent years to investigate aspects of football using tempo-spatial and network analyses. These approaches have gained traction within some professional teams to quantify and assess features of collective behavior. However, metrics employed are rarely created from, or clearly link to, domain expertise and as a result coaches may be hesitant of their value. Therefore, the aim of this study was to identify coach perceptions of spatial temporal and network metrics and identify the feasibility of an iterative and collaborative process to developing metrics. **Methods**: Two rounds of semi-structured interviews were conducted with three Scottish youth international UEFA Pro License coaches (age:47.0 ± 2.7 years) with a focus on aligning metrics with concepts and principles of play. An iterative approach was used centering around spatial-temporal and network metrics and their adaptation. Reflexive thematic analyses were conducted with final metrics categorized as *resonant* (accurately describing concept or principles of play), *relevant* (appropriate but with limitations that need improvement), or *hesitant* (skeptical of usefulness). **Results:** Across the ten recognized principles of play, nine metrics were identified and adapted to varying degrees. Resonant metrics included: network intensity (mobility), distance between defenders (discipline), triangles (support), team length and distance between deepest defender and goal line (depth). **Conclusion**: Coaches recognize principles of play within complex collective behavior metrics and should be encouraged to collaborate with analysts to develop support systems that may prove to be more valuable and usable.

Keywords: Soccer, collaboration, performance analysis, data analysis, decision making

Introduction

With increasing data collection in elite football, more sophisticated approaches are being developed to derive greater knowledge and insight [1]. Traditional approaches to data analysis have focused on players physical performance (e.g., information obtained by movement analyses) or on team performance (e.g., technical, or tactical event frequencies occurring in matches such as passes or dribbles) [2]. Due to factors such as the low scoring nature of football and subsequent fine margins to separate winning and losing teams, quantifying performance in this manner is challenging [3]. Subsequently, individual moments in football can greatly influence the match outcome and can lead to more frequent victories by teams who do not perform as well as their losing opponents [3]. Additionally, the continuous nature of football creates a dynamic environment where each player is constantly moving and adjusting based on the positions of their teammates and the ball [4]. The complexity can be challenging to summarize coherently such that performance analysts in football have traditionally supported coaching staff through video analysis supplemented with basic descriptive statistics [5]. Indeed, whilst evidence shows increasing use of more complex key performance indicators, a preference for simpler measures of performance such as shots on target has been demonstrated [6]. This mixed picture is further evidenced by the recruitment of data scientists by some elite teams to assist in the development and use of complex performance indicators that process positional and event data. This posits the question of how performance analysts, and data scientists can collaborate to create a system that is effective and actively supports coaching staff.

A barrier to achieving buy in from coaching staff is likely to include the mathematical nature of the complex metrics used in the literature base. Some studies have computed metrics based within principles of play using a range of techniques including computational measures relying on the position of player and networks of interactions where sequential order was integrated into the analysis [7]. Another approach is the FUT-SAT instrument presented by Costa et al. who created a notational tool based on player actions and underpinned by the 10 principles of play to evaluate tactical performance [8]. Whilst these approaches have demonstrated progression within football performance analysis, uptake of these tools and procedures appear limited. In a growing research field, there seems to be little collaboration with coaches regarding how the metrics used in this field can be applied in coaching. Gudmundsson and Wolle created tools while in close contact with coaches and analysts to

help shape analytical systems that were valuable [9]. However, a large section of the literature base performs research independently and without reporting cooperation with coaches [10].

Considering these issues, a monodisciplinary approach may not be optimal when providing performance analysis support for coaches. An alternative to this status-quo is co-production. Co-production is a process for capturing knowledge that is valuable in multidisciplinary contexts where in the domain of performance analysis, the analyst (the service provider) collaborates with the coach (the service user) to create higher value output. Whilst this method has gained popularity in finding solutions to an array of problems, there remains ambiguity in both the theoretical underpinnings [11] and the terminology with co-creation, co-design, and co-innovation often being used interchangeably [12]. Despite this, variations of co-production have been applied in sport and health contexts [13,14], however, there does not appear to be any literature that explores co-production in the context of performance analysis. Considering many coaches do not use more complex key performance indicators [6], collaborative approaches offer an avenue to integrate spatial-temporal and network analysis metrics into analysis provisions. Moreover, there is limited exploration of how coaches even perceive and use these metrics. Consequently, the purpose of this research was to identify coach perceptions of novel collective behavior measurements. This was done through investigating coaches' philosophy and principles of play and identifying how current measurements of collective behavior can be adapted to achieve buy in from a coach. The study drew on elements of co-production and comprised an iterative approach working with elite football coaches to present contemporary collective behavior metrics, explore the coach interpretations and their own philosophies and principles through qualitative interview and subsequently refine the metrics used.

Methodology

Study design

A framework for creating a tailored system to augment coach decision-making through performance data analysis and visualization was explored in this study. The framework comprised of an iterative process [13] (Figure 1), including standard collective spatial temporal and network metrics as a starting point, with modifications based on interviews with coaches based on their philosophy. Prior to data collection, institutional ethical approval was granted.

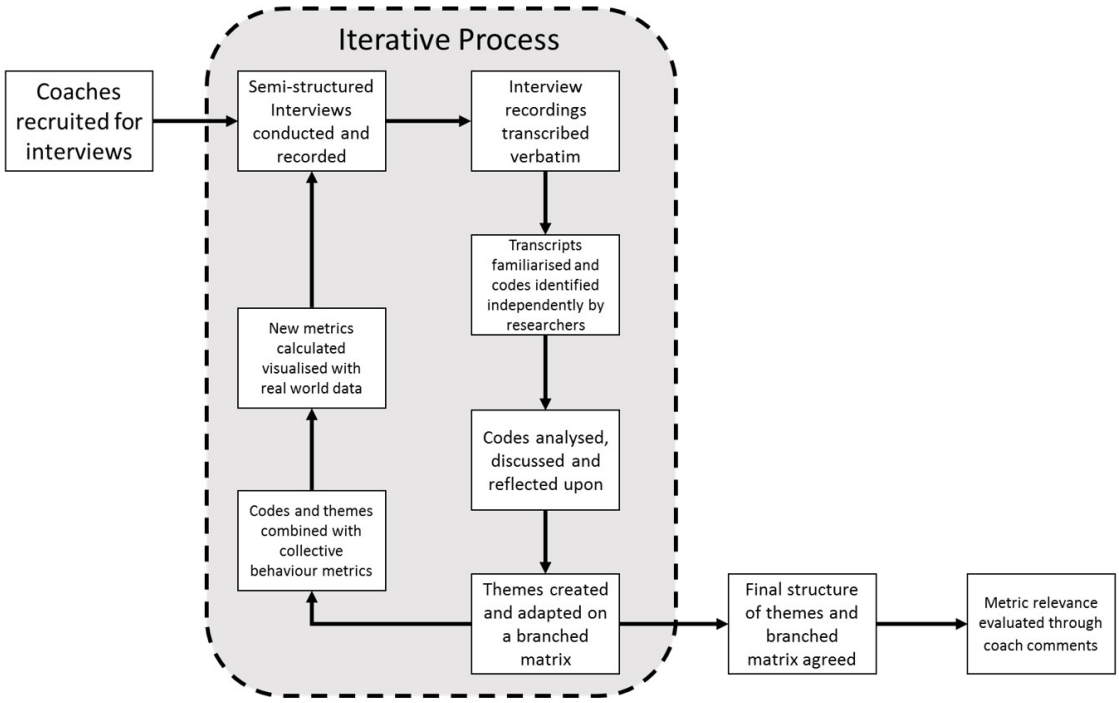

Figure 1. Schematic overview of the iterative interview process.

Participants

Purposive sampling was used to recruit three Scottish international football coaches (average age:47.0 ± 2.7 years) to allow for extensive information to be gathered [15]. Coaches had between 8- and 28-years coaching experience (average experience:18.3 ± 10.0 years) and held the UEFA Pro License qualification. Between the initial and follow up interview, one coach did not participate in the second interview due to changing jobs, resulting in a total of five interviews throughout the iterative research process.

Data Collection

Two separate phases of semi-structured interviews were used to gather the coach perspectives and to provide feedback on the initial (phase one) and modified (phase two) spatial-temporal and network metrics developed to quantify aspects of collective behavior (Figure 1). Open ended questions were integrated throughout interviews to allow for concepts to be explored [16] while giving the researcher some control over the process [17]. The interview questions (Appendix 2) centered on attacking, defending and transitions as well as spatial temporal principles including position, distances, spaces, and numerical relations along with network metrics seeking to gain further understanding of passing sequences.

Before each data collection phase, a fifteen-minute presentation was provided to the coaches. Phase one presentations provided an outline of common approaches used to describe

collective behavior, anchoring the discussions to relevant principles of play [10, 18]. Between interviews, metrics were adapted or created based on coach comments and a second presentation was constructed. During the second interview, coaches were provided quotes and interpretations of the initial interview and asked to comment on whether the calculated and visualized metrics were accurate and relevant or if concepts were incomplete. This approach has previously been used within coaching [9] and allows for scrutiny of interviewee quotes, facilitating adaptations to metrics and visualizations to better suit coach conceptualization [19]. All interviews and presentations were undertaken by the same researcher (MC). Interviews lasted approximately one hour and were recorded through Microsoft Teams with participant's permission, for transcription in verbatim.

Data Analysis

Reflexive thematic analysis was used to generate themes for both interview phases with a reflective log (Appendix 1) written to document the process [20]. Both researchers read through the transcripts multiple times to get a clear understanding of the raw data [20]. Following this, each researcher individually coded the transcripts prior an open and honest discussion to finalize coding [20]. Initially, the lead researcher collated and organized these into potential themes before discussing these with the research team [20]. These themes were reviewed to ensure they were representative of the coded extracts and fitted with the research question. Once agreed, themes were then defined prior to the formation of a final thematic tables/branched matrix [20]. Data were analyzed by two researchers (MC and MM) and both were involved in the creation of a reflective log to document the process (Appendix 1). Both have undergone training by their university to conduct thematic analysis and have previous experience of this process. This allowed for multiple analyst triangulation, ensuring participant information was interpreted appropriately and allowed for any conflicts or disagreements to be resolved within the research team [21]. The final thematic tables/branched matrixes can be seen in Tables 1 and 2. Based on the branched matrix and interviewee quotes, systems were created to measure the tactical concepts and principles of play highlighted as important. These were then computed using data from a Euro 2020 qualifying match and visualized using R and presented back to participating coaches. This step functioned as a member checking process to ensure credibility and trustworthiness [22], while forming the iterative process whereby domain expertise and evidence-based research are combined to create a robust process to inform practice [19].

153 **Table 1**. Initial thematic analysis identified from the first stage interviews.

Sub-themes	Themes	Main Themes
Disrupting Opponent	Penetration	Attacking
Creating Space		
Diamonds and Triangles	Support	
Balance		
Control		
Overloads	Width	
Attacking Shape		
Speed of Play	Mobility	
Movement		
Attacking Risk	Creativity	
Patterns of Play		
Decision Making	Attacking Transitions	
Counter Attacking		
Defensive Shape	Delay	Defending
Pressure		
Team Length	Depth	
Lines		
Cover	Balance	
Adjusting		
Compactness	Compactness	
Distances		
Triggers	Discipline	
Working as a Team		
Reaction	Defensive Transition	
Prediction of Transition		
Barriers to Development	Player Development	Team Performance
Learning Styles		
Learning Experiences		
Available Coaching Time		
Flexible Tactics	Match Preparation	
Pitch Size		
Opponent Ability		

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156 ## Discussion of Findings

157 This section provides an overview of the data derived from the iterative interviews along with
158 discussions of the initial and adjusted thematic analyses, based on coach comments.
159 Additionally, coach perceptions of proposed metrics and visualizations describing the
160 principles of play are discussed, identifying the most promising metrics for tactical
161 measurement based on coach opinion. Finally, a discussion on how these metrics can be
162 further developed to support the coaching process will conclude this section.

163

164 **Table 2.** Iterated thematic analysis identified from the second stage interviews.

Sub-themes	Themes	Main Themes
Diamonds and Triangles	Support	Penetration
Passing Options		
Angles		
Teammate Distances		
Coordination		
Overloads in Wide Areas	Width	
Creating Space		
Disrupting Opponents		
Attacking Shape		
Passing Speed	Mobility	
Contact Time		
Movement		
Risk	Creativity	
Breaking Lines		
Patterns of Play		
Deception		
1v1		
Defensive Shape	Compactness	Delay
Reaction		
Recovery		
Controlling Opponents		
Decisions		
Anticipation		
Length	Depth	
Lines		
Cover	Balance	
Overloads Near the Ball		
Adjusting	Discipline	
Triggers		
Time		
Distance to Opponent		
Working as a Team		
Pressure		
Barriers to Development	Player Development	Team Performance
Learning Styles		
Learning Experiences		
Available Coaching Time		
Flexible Tactics	Match Preparation	
Pitch Size		
Opponent Ability		
Game Context		
Player Strengths		

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166 *Iterative Thematic Analysis*

167 Questions in the first interview were structured around attacking, transition to defense,
168 defense, and transition to attack. These concepts were represented in the main themes from
169 the initial thematic analysis: *attacking, defending,* and *team performance.* The twelve themes
170 that feed into *attacking* and *defending* main themes share strong similarities with traditional

principles of play found in football literature [7, 23, 24]. As stated by Prickett these include five attacking principles: i) penetration, ii) support, iii) width, iv) mobility and v) creativity, and five defensive principles: i) delay, ii) depth, iii) concentration, iv) balance and v) discipline [23]. Attacking transition and defending transition were also identified as themes and are sometimes mentioned alongside the traditional ten principles [7, 24]. These ten principles of play were identified by participants, despite interview questions being designed without considering these concepts. The coaches all recognized these principles with coach 1 stating.

"I'm one that very much strives to stick to the principles of the game, you know, those are the constant strains."

This finding suggests that the principles of play previously identified are robust, however, the need for elite coaches to undergo education systems featuring these concepts may have played a role. The traditional principles also suffer from inconsistency in terminology used. This is demonstrated by coach 1 who lists the attacking principles as.

"depth, width, mobility, improvisation, penetration for your attacking ones."

The five principles highlighted by the coach align with the previously stated concepts, however, inconsistent terminology could lead to different interpretations. Other research has presented different principles of play that do not conform with the ten outlined by Costa [24]. Moreover, coaches will have differing opinions on how to implement tactical strategies, underpinned by principles. Establishing a unified framework for principles of play would help, but this is a challenge due to the varying perspectives of coaches. The initial thematic analysis can be seen in Table 1.

A finding from the initial interviews was that coach 1 stated that they had previously seen visualizations of team length before, however, did not use it to inform practice. Also, Coach 2 previously used network analysis to identify common passing behaviors of both their own team and the opponent, however, stopped the use of the analysis due to perceived limited value and resource required to record the data live. This relates to the final main theme of *team performance,* which branched into two themes: match preparation and player development. These factors related to how performance analysis provision can support the coaching process. Player development focused more on how training can be shaped to maximize development with sub-themes including learning experiences, available coaching time and barriers to development. These relate more generally to the holistic improvement of players and teams. Whereas match preparation identified how changing contexts can impact

desirable aspects of team performance from match to match. From the experiences of the coaches, their previous exposure to these visualizations and data had limited utility in preparing their team for a match or developing the players.

After completing the initial thematic analysis, metrics from the literature were selected and adjusted based on the coach comments. These were presented back in a second interview to confirm the interpretation of the coaches' comments were accurate and evaluate how representative the metrics were. From the transcripts of the 2nd interview process, the thematic analysis was adapted further. The biggest difference was changing the main themes of attacking and defending to *penetration* and *delay,* respectively. These were changed as *penetration* describes the main aims of the other themes in *attacking* while every theme of *defending* was related to *delay*. The transition themes were also removed from the second iteration of the thematic analysis as they were relevant across many themes. Instead, aspects of transition were combined as sub-themes within other concepts due to its importance in tactical organization across both attacking and defending. The changes were not limited to the removal of transitions from the themes and the promotion of penetration and delay. Of the 33 original sub-themes identified, only 16 (48%) remained unchanged in the second iteration of the table. Some of these changes were minor and were caused by the removal of the attacking and defending transition themes whereby sub themes were moved into other relevant themes. For example, prediction of transition moved from defensive transition to compactness and was renamed to anticipation to better suit the terminology used by coaches. Only 4 (12%) sub themes were rephrased and another 4 (12%) were removed completely where words were either too similar to the themes they were allocated or were too broad and as a result not informative. For instance, 'decision making', could be perceived as relevant in each theme and was consequently removed to avoid sub-themes bleeding across the thematic analysis.

Such an effect is expected when evaluating tactical principles in a complex dynamical system such as a football match. Indeed, all these concepts are interconnected, naturally causing some of the initial sub-themes to bleed into multiple themes. To minimize the impact of this effect, 3 (12%) of the original codes were split into 6 (14%) of the 41 total sub-themes identified in the second iteration of the thematic analysis (Table 2). For example, distances were commonly referenced in the initial interviews. However, after devising the tools and presenting them to coaches, it appeared that the distances occupied two distinct themes: discipline and support. Consequently, distance to opponent and distance to teammates were placed in the themes respectively. Finally, a total of 9 new sub-themes were added to the

thematic analysis based on the coaches' comments in the second interviews that related distinctly to each principle of play.

Table 3. Overview of metrics summarizing principles after the iterative interview process and feedback from coaches.

Metric	Measurement	principle	Coach perception	Coach quotes
Network intensity	successful passes/time in possession [41,42]	Mobility	Resonant	"I love it, I think it's absolutely brilliant and so critical in terms of player development, team development, winning games."
Distance between defenders	Distance between defenders from identified players in defense position going from the left of the pitch to the right of the pitch [43,44]	Discipline	Resonant	"the whole team needs to get back out. It's, for me really, really important to get those adjustments. And always, you can't… you can't take risks."
Triangles	distances, angles and area of a triangle described by 3 pre-selected players (e.g., midfielders) [43,45-47]	Support	Resonant	"The distances are really important. But I also think it's the players that that need to sort understand that, you know, you don't just move to support the ball, if you're part of the Midfield three like that."
Team length and distance between deepest defender and goal line	Distances calculated in the x-axis only from the deepest defender to the furthest forward attacker (team length) and the goal line [48-50]	Depth	Resonant	"I personally, coach my teams in a similar way. If we were under pressure, then I would want in that scenario, I would want my striker to be back as well"
Surface area	Calculated from the area of a convex hull of the outfield players [29, 30]. Differences are measured between 1 second before loss of possession, loss of possession, 2 seconds after loss of possession and time taken until 600m^2 is reached.	Concentration	Relevant	"I think the only thing I would add to that [author] is on the tactical instruction of the coach and the team, knowing whether on those transitions…"
Team width	Distance along the y axis between player furthest right, and player furthest left on the field	Width	Relevant	"at a higher level of the game, they'll start to do things that are very different and much more complex"
Distance dyads, time to contact, and passing lane	Distance pressure calculated through pressure variable from Link [32]. Time pressure calculate	Pressure	Relevant	"I agree with your description of the pressures. What I would add I'm sure you're aware of it is, in my opinion, it's

	through time to contact from player in possession and closest defender [33]. Passing lane identified from available players to pass to who have a passing lane greater than 10° [34].			the decision from the [Team1] central defenders not to pressure once the transition happens."
Numerical Advantage	Effective area of pitch described by all outfield players is divided up into 7 areas as shown by Vilar [37]. Difference in the number of players in each team within each section is calculated.	Balance	Hesitant	"I would say probably needs a little bit. A little bit of work."
Pitch control and number of outplayed opponents	Points on the pitch closest to each player adjusted based on the movement speed and direction of each player [52, 53].	Penetration	Hesitant	"You can show lots of pictures of good examples. But at the end of the day, it comes down to quick time decision making and execution."

Coach Perceptions of Collective Behavior Measurements

The coaches' perceptions of metric and visualizations presented to them in the second interview that were constructed and adapted from approaches in the literature-based on the comments made in the first interview. A grading system was used to categorize how coaches responded to each metric. If coaches demonstrated enthusiasm towards a visualization or identified that the measurement was fully descriptive of a principle in football, then it was labelled as *resonant.* If the metric was identified as accurately describing a concept, however, the coach identified limitations or aspects that needed improved, then it was labelled as *relevant*. Finally, if a coach was skeptical of how useful a metric would be in practical settings or identified situations where the model was inaccurate at representing the principle then it was labelled as *hesitant*. Table 3 provides an overview of the 9 visualizations presented to the coaches, highlighting which metrics show most promise, along with summary quotes supporting the categorization of each metric.

Resonant Metrics

Mobility

The mobility principle was discussed several times in the initial interview phase. Naturally, mobility relates to player movement and was suggested as being linked to the concept of support, where teammates must move into appropriate positions to provide passing options.

However, mobility also relates to actions on the ball and how a team can move the ball at pace. Coach 3 emphasized the importance of this:

"that's what the top players can do, they can, they can play at speed, they can do everything quickly, control the ball pass the ball, turn."

This relates closely with the measurement of network intensity, explored by Grund, measuring the rate that teams pass the ball [32]. This was presented to coaches as a mean across individual matches, as well as during attacks with comparisons between and within matches. This measure received a positive reaction with coach 3 stating:

"I love it, I think it's absolutely brilliant and so critical in terms of player development, team development, winning games."

Evidence from Grund found a link between successful teams and high network intensity. However, more investigation in this metric is required to inform training [25, 26]. Despite reacting positively, coach 3 provides more detail.

"…it's not just the speed of the pass, it's the contact time in between, you know, the amount of time it takes a player to control the ball and play the ball."

This suggests that network intensity may not fully describe the team's ability to move the ball quickly. By splitting passing actions into control-time and pass-time, and incorporating starting and ending positions of passes, a deeper understanding might be obtained.

Discipline

Another measurement coaches responded positively was the distances between defenders. This relates to discipline, a principle emphasized by the structure of the defensive unit. Trigger points were identified as a sub-theme relating to discipline as coach 3 states.

"We speak about where we're going to engage with the opposition, whether it's at the top of the circle, whether it's the halfway line, the distances from side to side, are as important as from front to back and back to front… it comes from, from practice, and players being good enough to do what they've been asked and recognize it. And also disciplined enough to do it."

Through discussions with a coach, these can act as transition between defensive states of organization and pressure. However, the measurement presented to coaches focused on

defensive structure. In the visualization presented (Figure 2), coach 3 believes players are not adjusting properly.

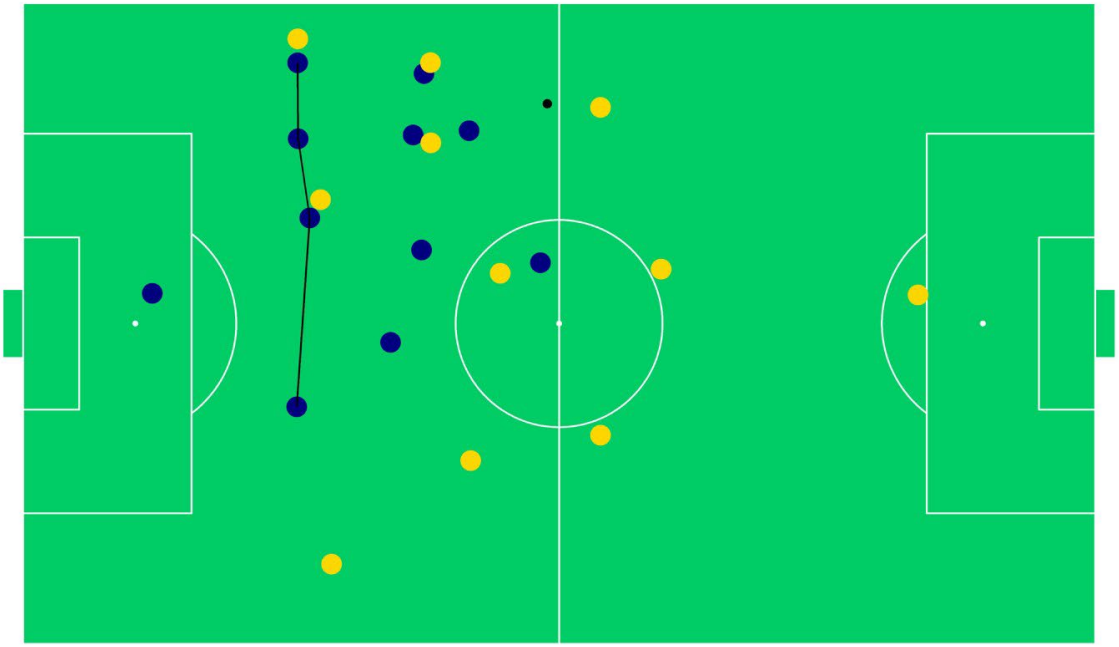


Figure 2. Top-down visualization of players in team 1 (blue) and team 2 (gold). Lines connecting defenders in team 1 show distance between defenders as they are positioned across the pitch.

"I don't think that's correct. I personally don't think the [Team 1] players are adjusting enough. Like for me, they need to be adjusting more aggressively, especially in the right back."

Interestingly, there was a difference of opinion between coach 2 and coach 3 in the example shown. Coach 2 is happy with large gaps appearing based on contextual information.

"we're quite happy for the distance between the centre back and the fullback to be there, because we know that that central midfielder can drop in there as well."

Whilst coaches agreed with the importance of this concept, it highlights the need for systems at clubs to be tailored to individual coaches' principles and philosophies as there is no universal agreement on nuances held within each concept.

Support

The support principle centers around how players organize themselves to provide passing options. Coach 1 highlighted the importance of angles.

"we play on those sorts of angles, you know, you've got that ability, you know, to see where the balls coming from, if it's coming from a deeper position and also the goal you want to attack so you can make a decision on how to use the ball next."

This connects to another sub-theme identified as diamonds and triangles. Coaches emphasized these are important structures created by the players to help teammates. Angles and distances have been used in multiple investigations, researching the coordination of player actions [27-31]. Conceptualizing players in groups of 3 and calculating properties of the triangles they form including distances, angles, areas, and positions on the x-axis can help quantify team cohesion. These properties are visualized in Figure 3. Whilst measurements of distances and angles have predominantly been identified through dyadic relationships [28, 31]. Coaches agreed that triangle formation was an important aspect of team performance with emphasis on the distances and angles between the players.

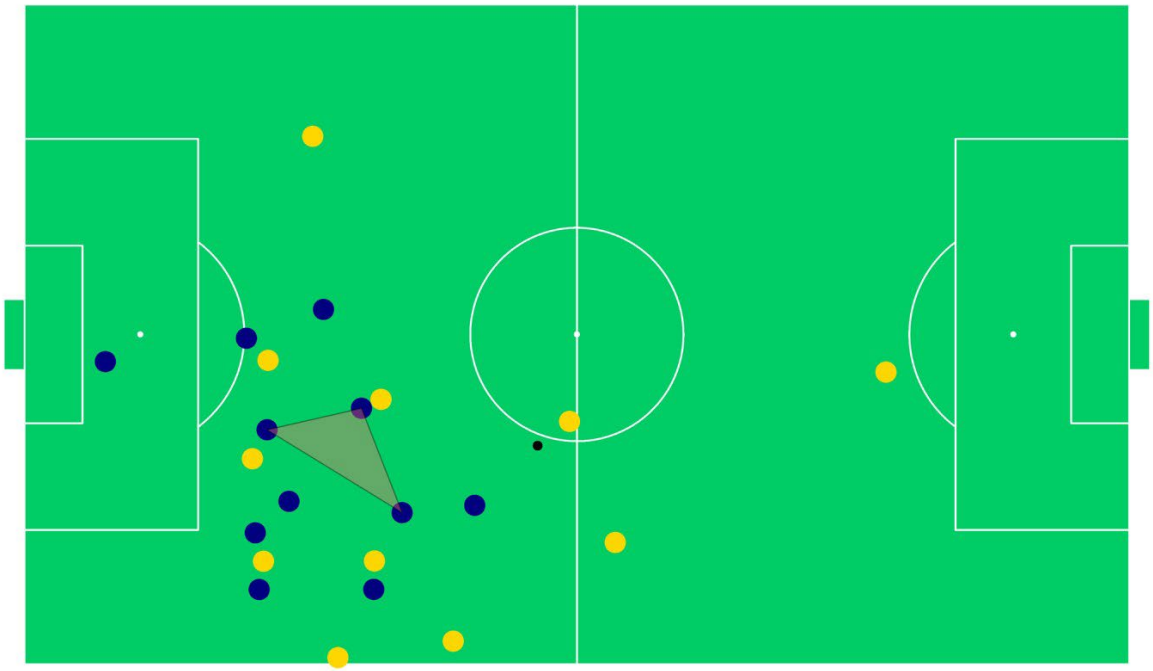


Figure 3. Top-down visualization of players in team 1 (blue) and team 2 (gold). A triangle is annotated between three central midfield players in team 1, visualizing the distances between the players and the area.

The triangle described by three central midfielders was presented and was identified in the follow up interviews as the most critical triangle in the formation, however other triangles were also stated as useful. Coach 3 highlighted the triangular shape in the center midfield is also important when defending.

"...whether the triangles match, because not sometimes it's just say, my team are playing two holding midfielders and the number 10. So, in my, the way, I see the game that's triangle up and the other team might be playing triangle up as well, which means there's not, it's not man for man, the triangles don't match."

Therefore, triangles, and their relationship between attacking and defending teams may be important, however, specific measurement for how these relate to each other and what constitutes successful and unsuccessful organization needs to be identified. Clemente et al previously investigated defensive triangles, specifically looking at the area [32]. However, these measures have not been comprehensively explored.

Depth

The final theme and visualization that resonated with coaches was depth. this relates to the position of players along the pitch. In this sense, many coaches perceive "*lines*" in their team. Indeed, this aspect was presented in the initial interviews through group centroids along the x-axis as shown in Figure 4. This visualization received positive feedback, however, coach 1 mentioned an alternative measurement that appears in the literature often named team length [33, 34].

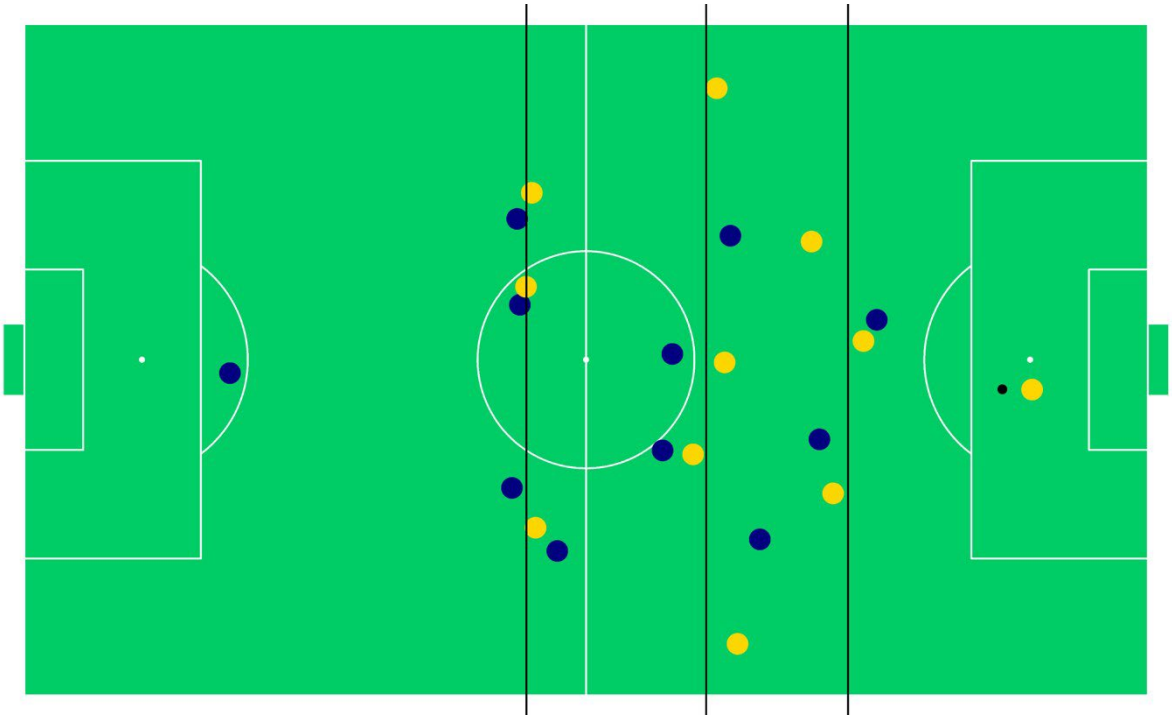


Figure 4. Top-down visualization of players in team 1 (blue) and team 2 (gold). Three lines demonstrate the average x coordinate on the pitch of the defenders, midfielders and attackers respectively.

"I've seen similar ones where they kind of always have a constant distance from the deepest defender, you know, maybe one of your center backs is behind the rest of the line. And the furthest forward player, you know, is that at 35 or 40 meters."

The distance between the furthest back and the furthest forward player accompanied by the distance between the deepest defender and the goal line was measured [34] as shown in Figure 5. In the second round of interviews, coaches stated they actively coached this concept and that both visualizations aligned with their perception of the principle.

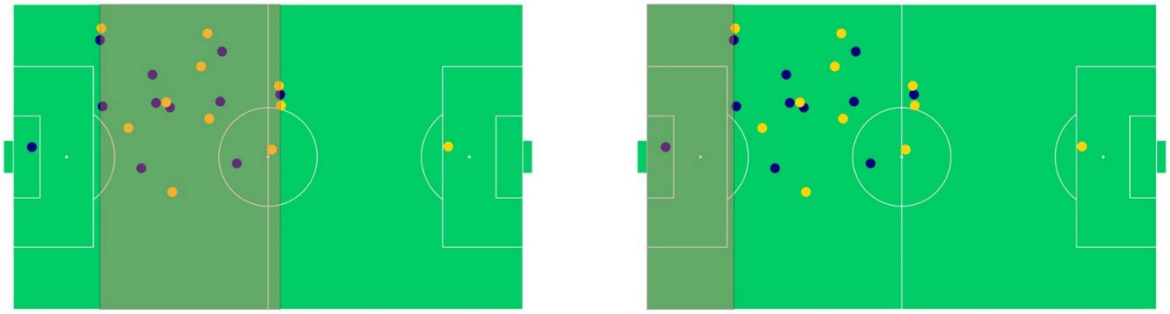


Figure 5. Top-down visualization of players in team 1 (blue) and team 2 (gold), (a) Team length is shown by the box that encompasses the width of the pitch and covers the furthest forward and furthest back outfield players in team 1, (b) Space behind the defence is shown by the box that encompasses the width of the goal and goes from the deepest defender in team 1 to the goal line.

Relevant Metrics

Compactness

Common measures to evaluate the compactness of a team include surface area, stretch index and team spread [35-40]. These metrics demonstrate similar measurement patterns when observing intricate attacks [40]. The sub-theme of defensive shape was identified as a component of compactness; therefore, surface area was selected due to its alignment with this term (Figure 6). However, simple analyses of surface area along with other measures have demonstrated they are not sensitive enough to differentiate between successful and unsuccessful team compactness [40]. To measure this principle in a meaningful way, the coaches' conceptualization of it must be understood. Coach 3 highlighted the importance of speed when returning into defensive shape after transition.

"how quickly you can get back in shape after you lose the ball. And that is something that we coach."

When discussing these concepts, coaches emphasized the importance of "anticipating" and "reacting to" the loss of possession. Therefore, these aspects are likely relevant when evaluating defensive shape through surface area. The output signal of this measurement is the area encompassed by the outfield players described in figure 6. Anticipation was measured by the difference between surface area at the loss of possession and 1 second before. Reaction was measured as the difference between the surface area at the loss of possession and 2 seconds afterwards. Finally, the time to get into a defensive shape was recorded and measured as the time between losing possession to reaching a surface area of 600m^2. This value was selected based on previous data examining other international teams surface area [40]. Coaches agreed this model made sense; however, this value requires additional contextual information to be representative as coach 3 highlights that an immediate return into a defensive shape is not always desired.

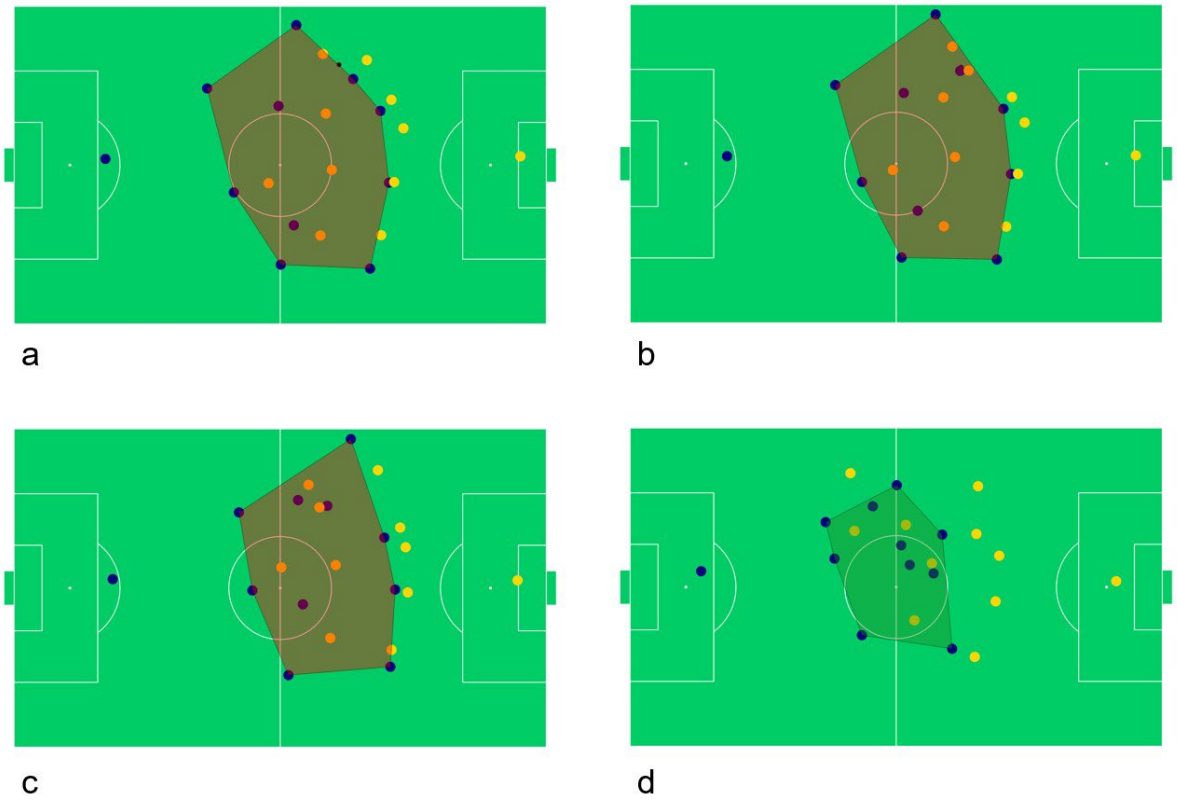


Figure 6. Top-down visualization of players in team 1 (blue) and team 2 (gold). Surface area is calculated as the convex hull of the outfield players, visualized through the red polygon. The polygon describes the surface area of the team (a) 1 s before possession loss, (b) at possession loss, (c) 2 s after possession loss, and (d) when an area of 600 m^2 has been reached with the polygon turning green.

"what is the objective? to get back into shape, and be compact as quickly as possible, like you're speaking about, or is it to try and win the ball back immediately and to actually counter press?"

Width

Width is a principle simplistically measured in the literature base [34, 36, 37, 40, 41, 42]. This metric measures the distance across the y-axis from the player furthest right on the pitch and the player furthest left. This output is shown in Figure 7 and is often combined with the team length measurement already discussed.

Coaches believed this was an important attacking aspect when presented the visualization. However, the example provided was specifically chosen to be a situation where the team were demonstrating low levels of width but were still successful in scoring. Coach 2 believed that they were performing complex actions due to the tactical set up of the opposition.

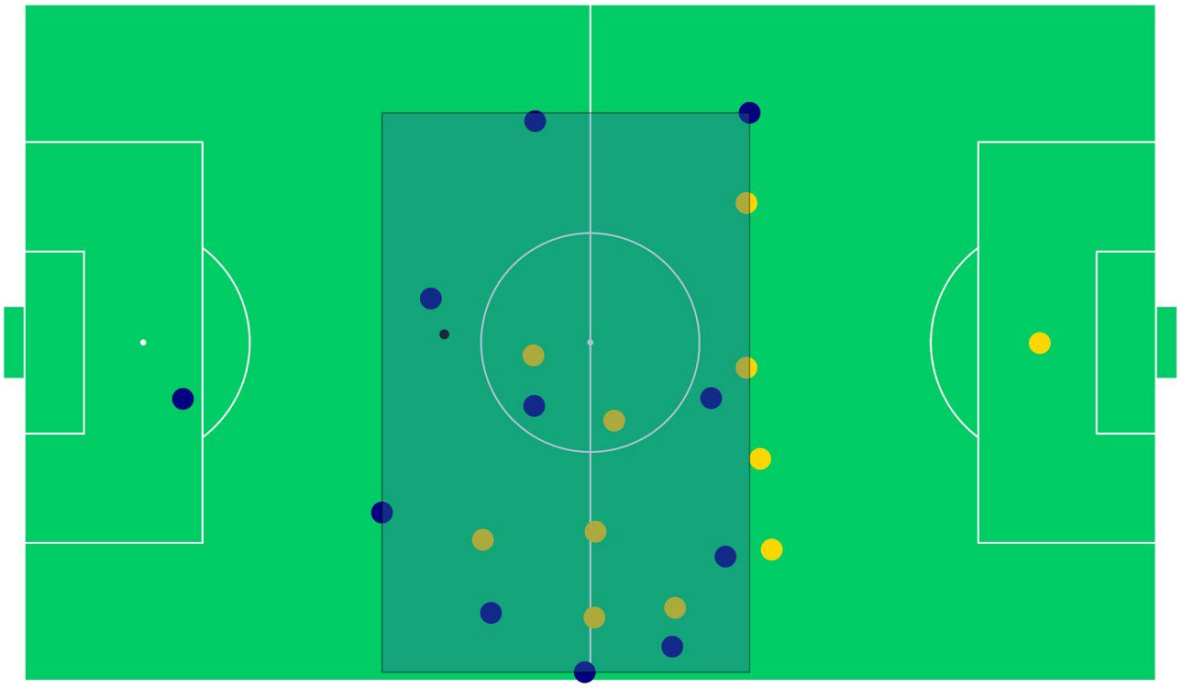


Figure 7. Top-down visualization of players in team 1 (blue) and team 2 (gold). Width is demonstrated by the box surrounding a box described by the players closest to the touch lines and goal lines.

"...you can be really expansive in terms of your width and stuff like that. But if they sit in and are happy just to defend whatever comes in, then you have to start going in and trying to manipulate and get movements."

This suggests that applying width directly through players positioning themselves close to the edge of the pitch was not having the desired effect. One of the sub-themes of width is creating space and having players in wide areas should facilitate the creation of space in central areas. Coach 3 highlights that in this situation, the attacking team still have space to create viable passing options:

"…even though [team 2] are compact, there are still pass options through them available."

This proposes that width as measured in this example is not comprehensively evaluating the success of a team in destabilizing the opponent. Considering other sub-themes such as overloads in wide areas, creating space, and disrupting opponents might help develop this metric in its evaluation of how teams use width to create space and penetrate defenses. Alternatively, incorporating overloads in peripheral areas may evaluate a team's ability to penetrate opponents out wide.

Delay

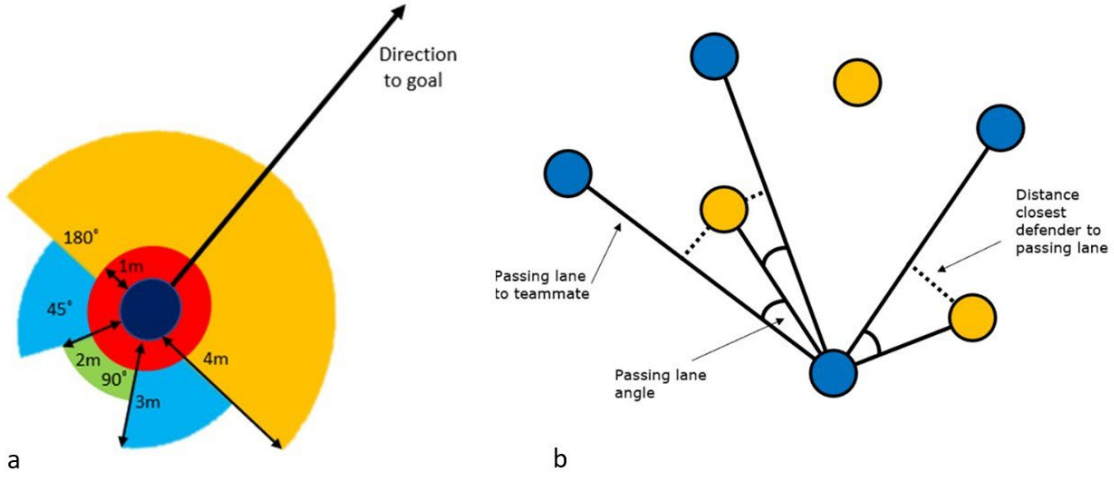
After the initial interviews, delay was identified as a theme. However, in the subsequent interviews it was promoted to a main theme. The following metric is still relevant to performance and fits closely into the theme of discipline. The metric was initiated based on comments identifying the role that applying pressure plays in delaying the opponent. Coach 1 states:

"the first thing we have to do is delay the opposition from progressing towards our goal. So again, different applications doing that, you can apply pressure to, you know, the opponent…"

Across the three interviews, the coaches highlighted three ways which a player on the ball can be placed under pressure. Most prominently, the distance between the players was emphasized as critical in delaying the opponent. However, other factors including the time a player has on the ball and the number of passing options available. Three models were used and adapted to evaluate the total pressure being applied to a player. To evaluate the space pressure, the system devised by Link et al to measure pressure relating to danger was used [43]. Time pressure was evaluated by the time taken for the closest defender to reach the player on the ball at their current speed [44]. Finally, decision pressure identified how many simple passes to teammates were available. This was calculated using passing lanes whereby a simple pass

438 required an angle > 10° for each player [45]. Diagrams describing calculations for space and
439 decision pressure can be seen in Figure 8.

440 The three measurements were scaled to represent very high pressure as the value approached
441 1 and very low pressure as the value approached 0. A weighting procedure was then
442 intuitively applied where space, time and decision pressure values were multiplied by 0.7, 0.2
443 and 0.1 respectively before summing together to output the total pressure. Space pressure was
444 selected as the main component due to previous use as a measurement of pressure [43]. An
445 animated bar graph was presented to the coaches with the accompanying video footage and
446 top-down x y coordinates of the players and ball (Figure 9). Coaches stated this made sense
447 and agreed with the model as accurately describing the pressures on the pitch. However, the
448 angular threshold of 10° for the decision pressure variable along with the weightings are not
449 empirically supported and further analysis is required to refine this technique. These concepts
450 can then be used to accurately understand the pressure that players are under when playing in
451 matches and consequently tailor training to replicate what they will experience in matches.



452

453 **Figure 8**. Pressure models, (a) space pressure model, where subzones are created around an
454 attacker based on the angle to the centre of the goal. Pressure is calculated based on which zone a
455 defender is in, and their distance to the attacker. The closer a defender is, the higher the pressure, (b)
456 time pressure measured through passing lanes are identified by the line from the attacker in
457 possession to their teammates. The angle of a passing lane is calculated between the receiver to the
458 defender closest to the passing lane.

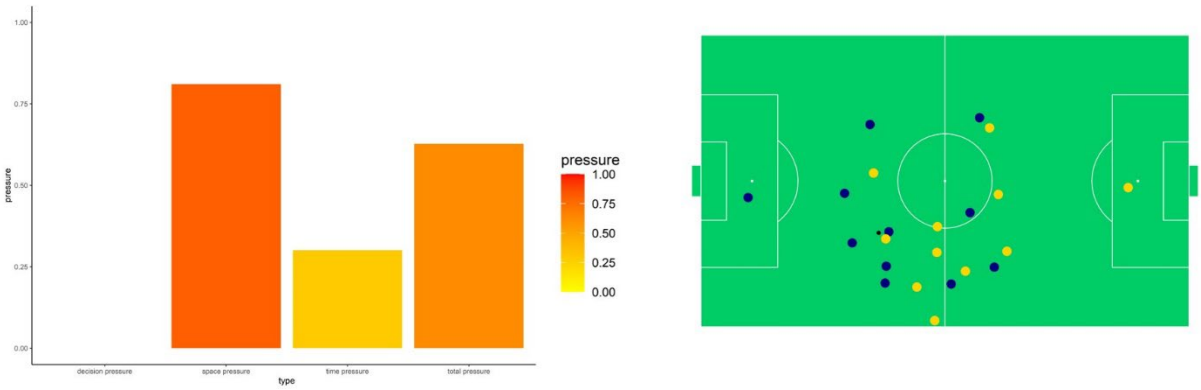


Figure 9. Top-down visualization of players in team 1 (blue) and team 2 (gold) with the ball in black. The accompanying graph shows the total pressure calculated from the space, time and decision pressure on the player with the ball at each touch. Pressure is interpolated between touches.

Hesitant Metrics

Penetration

Penetration was also changed from a theme to a main theme. Similarly, the proposed metrics may still be relevant, although needs adapted further as coaches were skeptical of its use. The number of outplayed opponents was used to describe penetrative actions adapted from Rein et al [46]. In their analysis, passes were examined to identify the difference in number of defenders closer to the goal line at the start and end of a pass. However, this outcome-orientated value does not explain how a team successfully progresses through the opposition and was used as a guide to identify instances deserving further analysis. Voronoi cell computations have been used to examine passing actions and behaviors of high-level teams when successfully penetrating opponents through creating space [47]. This mathematical model identifies the areas on the pitch closest to each individual and its relevance aligns with a comment from coach 1.

"how can we get runs that will, in a sense destabilize, the opposition's organization, and then use the ball to find those spaces or opportunities to penetrate."

Voronoi cell computations, or variations of the calculation termed as pitch control have been suggested to identify likelihood of pass success based on the position a player is in and the space they occupy relative to everyone else [47]. Several unique calculations of Voronoi cell computations have been implemented across the literature, whereby player movement speed, player characteristics, the offside line and the ball trajectory have been implemented to

evaluate actions such as passes [46-50]. A simple model was presented to the coaches whereby player speed was layered on top of positional data to identify areas of the pitch a player can pass the ball to successfully find a teammate. Figure 10 demonstrates the output of this model while estimating the probability of a successful penetrative pass that outplayed 6 opponents with a 55% likelihood.

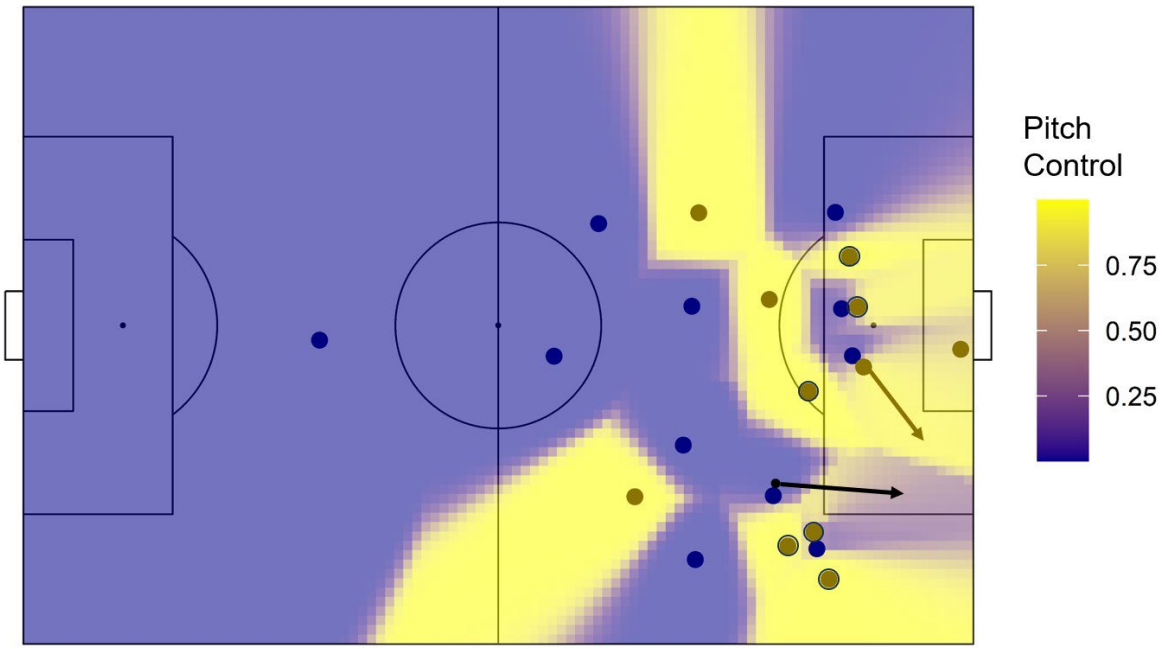


Figure 10. Top-down visualization of players in team 1 (blue) and team 2 (gold). Pitch is tiled with each square and coloured depending on the likelihood of the blue team having possession (values closer to 0) or the gold team having possession (values closer to 1) when the ball is played into each area. Outplayed players are highlighted. Movement is shown on one defender to highlight their movement into a deeper position and not be counted in the outplayed opponents.

When presenting this to the coaches, coach 3 was surprised by how low the success percentage of the pass was based on the calculation and how they perceived the pass in the video. That might indicate that a more sophisticated model is required to accurately predict the success rate of this pass. Moreover, the usefulness of this model for informing training practices is unclear. Coach 2 emphasizes that identifying and showing previous situations where this is done effectively or ineffectively does not necessarily translate to players capable of identifying opportunities and executing penetrative actions successfully.

"You can show lots of pictures of good examples. But at the end of the day, it comes down to quick time decision making and execution."

Balance

Coaches frequently discussed "*overloads"* as a tactically relevant concept. This occurs when a subgroup of players in a section of the pitch form numerical superiority in a game situation, for example creating a 2v1 or 3v2. This relates to the defensive principle of balance, where the defending team seeks to distribute their players so that the opposition is unable to create a numerical advantage. All coaches highlighted overloads in the wide areas as an effective tactic to creating dangerous chances. Coaches also identified that overloads in the middle of the pitch were desirable but more challenging to create. Different models of classifying zones for numerical advantage have been applied in the research. Clemente et al used 12 static zones with 4 sections along and 3 sections across the pitch [51]. However, the model selected to show to coaches used 7 dynamic zones that shifted across the pitch relative to the outfield players as shown in Figure 11 [52].

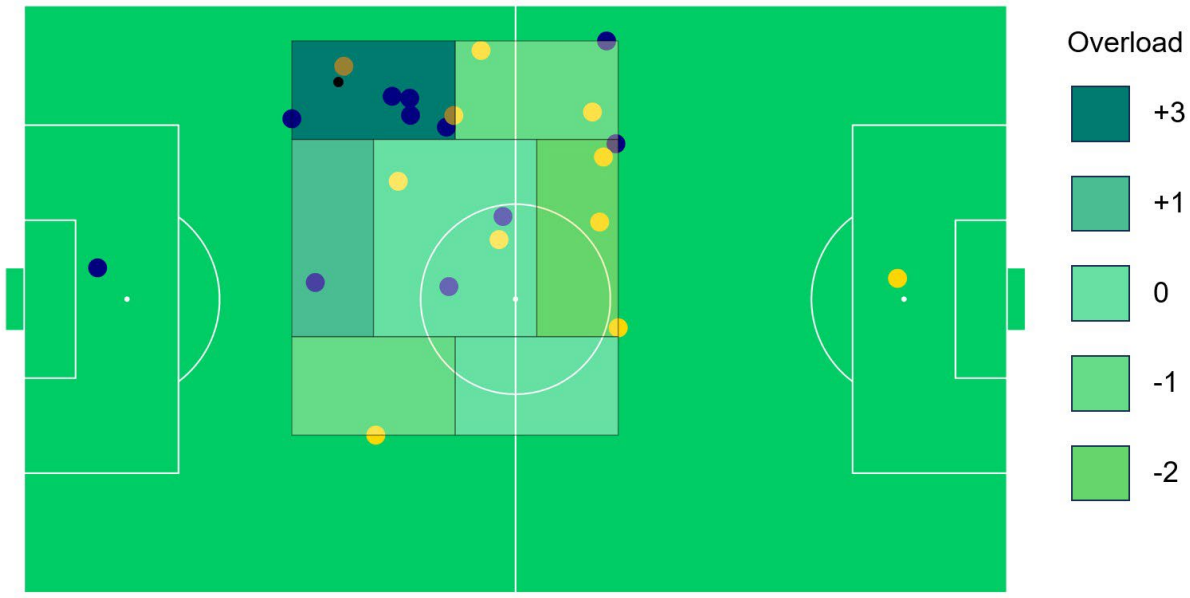


Figure 11. Top-down visualization of players in team 1 (blue) and team 2 (gold). Zones, based on the length and width of all outfield players are coloured based on the numerical advantage of team 1.

Coaches believed this model was not representative of the situation presented to them. In the example shown in figure 11, the numerical advantage is identified as a 4v2 in favor of the blue team. However, coaches identified that they perceive this situation to be representative of a 1v1, as only one defender stands between the highlighted player and goal. Although, coach 2 suggested that it may be useful with some refinement.

"I like the thought process of it. It's more of an active zone as opposed to static zones"

Creativity

Creativity was a recurring theme throughout the interview process. Initially there was no clear method of quantifying or representing the principle. In the second interviews coaches were asked to expand on the principle of creativity. In turn, coaches identified that creative behaviors often lead to penetrative behavior. Coach 2 states.

"I think when something is creative it penetrates a backline or the end result as potentially maybe getting in behind or creating an overload situation."

This indicates that metrics used for penetration might be helpful in quantifying some aspect of creativity. However, coaches were hesitant on their value, so would require adaptation. Based on the sub-themes identified, other measurements could investigate the dynamics of 1v1 situations, as some research has already investigated [27, 53, 54]. Additionally, the sub-theme of deception, might provide some insight into a team or groups ability to play through the rate of change in distance between team centroids [54]. Although, such a metric may not align with how coaches conceptualize such a principle.

Future Applications

This methodology identified that novel metrics evaluating collective behavior are representative of some concepts as understood by coaches. A critical question remains, can these be used in practice to inform coaching and improve performance? Analysts should look to establish normative data for metrics that resonate with their coaches. Initially this would describe team performance within tactical components. This can highlight team vulnerabilities and inform training design for preparation against specific opponents. An understanding of how the values and patterns of metric change as constraints are adjusted could then be used to gain deeper insight in development of an overall performance analysis tool. Long-term observations could become relevant for developing youth players, creating pathways, and learning experiences that prepare players for competing at the highest level.

Challenges remain in applying spatial-temporal and network analysis metrics. Considering the coaches working in the same organization and undergoing similar coach education had some minor differences in perceptions. This difference has the potential to be greater in

coaches with very different educational and cultural backgrounds. Consequently, metrics tailored to the individual are most likely to achieve buy in from coaches. However, many coaches may be hesitant to participate in the creation process due to time commitments. In this investigation, coaches only contributed two hours of their time, but a fully refined set of metrics would likely require numerous interviews, along with implementation trials. Moreover, practitioners would be required to continue with their current responsibilities whilst creating these tools. Based on this investigation, the time requirement for each iteration was approximately 80-100 hours of work, making the development a slow process. Future refinements, however, may be less time consuming and once the system is created, valuable metrics can be fed back immediately after a session.

From the interviews, many principles and concepts are measurable using spatial-temporal and network analysis metrics and as such further study is recommended. A collaborative approach might be valuable for analysts to consider, helping to achieve buy in from the coach and develop metrics informing the decision-making processes. A limitation of this research is that the application of these novel metrics was not tested, limiting the evaluation of a comprehensive co-creation process. Whilst this research presents evidence that should encourage analysts to co-create collective behavior metrics through positional and network data, more research is required to fully evaluate the utility of this process, especially considering the small sample of coaches used in this investigation. A range of analysis approaches including approximate entropy [55], relative phase [56], and vector coding [57] have been explored in the literature. Practitioners should remain cautious when applying more advanced mathematical procedures, however, this research suggests that understanding coach perceptions might be a valuable approach to start a collaborative process and create individualized metrics that the coach will find value in.

Conclusion

This investigation demonstrates a methodology for collaborating with coaches to create a unique and tailored performance analysis system that integrates novel metrics applying social network and spatial temporal analyses to quantify principles of play. Coaches suggested that network intensity, distance between defenders, team length, space behind the defense and triads were the most promising metrics. From the interviews coaches highlighted these models can be useful for improving team performance with emphasis on enhancing training sessions. Further iteration and practical application of the systems being used are required to

maximize the utility of applying novel collective behavior systems. The models require integration with contextual variables to comprehensively describe and explain the decision-making processes in football.

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