# Spatial-temporal metrics to assess collective behaviour in football: a systematic review and assessment of research quality and applicability.

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2021

# Spatial-temporal Metrics to assess Collective Behaviour in Football: A Systematic Review and Assessment of Research Quality and Applicability

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Abstract

Extensive research has been conducted to investigate collective behaviour of football players using spatial-temporal data. The purpose of this systematic review was to synthesise and evaluate the applicability of this research by reviewing information presented in previous studies and its capacity to clearly describe the analysis approaches and practical applications of findings. Eighty-five studies were included in the review with approaches assigned to 4 categories of metrics (1: spaces; 2: distances; 3) position; 4: numerical relations) and 2 analysis methods (predictability and synchronisation). The review identified that authors descriptions of metrics generally focussed on operationalised definitions and provided limited translation to game scenarios or coaching strategies. Similarly, a substantive percentage of studies (22%) did provide any practical applications, and where these were provided, they were generally broad and provided limited actionable information that could be used directly by practitioners to inform training. Where specific applications were provided these were consistent with a dynamic systems perspective of collective behaviour and focused on organismic, environmental and task constraints that could be manipulated. The findings of the present review highlight the innovative practices of the research base and identify several areas for development to increase understanding and uptake in practice.

Keywords: dynamic systems; predictability; synchronisation; constraints based.

## Introduction

Performance analysis is an evolving discipline of sport science that aims to use innovative approaches to instrument coach decision making and athlete performance (Mackenzie and Cushion 2013; Sarmento et al. 2018a). Technologies such as global positioning systems (GPS) and semi-automatic video tracking have been used extensively in elite sport for a prolonged period and enable insights into performance to be captured (Cummins, Orr, O'Connor & West 2013; Castellano, Alvarez-Pastor & Bradley 2014). It has also been reported that GPS data have been used primarily to quantify physical outcomes and, to a lesser extent, identify external factors that influence the physical outcomes measured (Castellano et al. 2014). However, team sports are highly complex and it is recognised that descriptions of simple behaviours such as number of sprints and total distance achieved provide limited insight into the functioning of a team across collective units (McGarry 2009). Contemporary perspectives that view team sports as complex systems identify a need to focus on interactions between players in different match and training settings. Interactions can routinely be described by the positioning and motion of players relative to each other (Travassos, Araujo, Correia & Esteves. 2010). More abstractly, Duarte, Araujo, Correia and Davids (2012) described sports teams as superorganisms composed of teammates continually communicating to help the team function as a unit. Importantly, communication is not limited to routine verbal instruction, but also includes the interrelated dynamics of player motion. Based on these perspectives, player tracking technologies can be used within a systems framework and the generated spatial-temporal data used to provide insight into collective behaviours that may lead to better decision making to improve performance (Low et al. 2019).

One sport where spatial-temporal assessment of player collective behaviour is developing rapidly is football (Sarmento et al. 2018a). Conventional performance analysis approaches such as frequency analysis can be considered simple methods that describe outcomes of collective behaviour. However, due to the lack of contextual information describing the underlying processes that led to these outcomes, conventional approaches are limited in their ability to inform decision making (Tenga & Sigmundstat 2011). As a result, integration of spatial-temporal data into collective behaviour approaches is increasingly being developed to explore models that best describe underlying processes and subsequent outcomes generated. However, with up to twenty-two players plus substitutes participating, a wide range of approaches to quantify and assess coordinated behaviour in football exists. This range reflects the diverse research produced by authors over the last decade (Bartlett, Button, Robins, Dutt-Mazunder & Kennedy 2012, Clemente, Couceiro, Lourenco Martins, Mendes & Figuiredo 2015, Castellano, Fernandez, Echeazarra, Barreira & Garganta 2017, Coutinho et al. 2019b), with Sarmento et al. (2018a) identifying collective behaviour analysis and associated metrics as one of the most innovative and important trends for football analysts. The large range of approaches to quantify collective behaviour also appears to be influenced by the overarching theoretical framework adopted (e.g. dynamic systems theory, sociobioglogy) and the specific backgrounds of researchers involved. However, it has been argued that any approach should ultimately be valuable to practitioners and coaches providing relevant information that can be used to improve performance through adaptations to training design or match play (Memmert, Lemmink & Sampaio 2017, Sarmento, et al. 2018a).

To date there has been limited attempt to synthesise research investigating spatial-temporal metrics and assessment of collective behaviour in football. The first systematic review was conducted recently by Low et al. (2019) and provided a comprehensive overview of the empirical research. A total of 77 studies featuring a mix of observational studies (n = 34) and field-based experiments (n = 43) with mostly male professionals were included. Low et al. (2019) identified 27 unique spatial-temporal metrics that were separated into four categories (position; distance; spaces; and numerical relations). Additionally, the authors' delineated between linear analysis methods performed on these metrics (e.g. mean, standard deviation and coefficient of variation) and non-linear analysis methods quantifying either predictability (e.g. approximate entropy, sample entropy and dynamic overlap) or synchronisation (e.g. relative phase, cross correlation, cluster phase and vector coding). Finally, the authors reported that investigations of collective behaviours were analysed at all system levels including the dyadic, sub-group, team, and match levels. Collectively, the review produced by Low et al. (2019) provided a clear and effective framework to synthesise findings from what initially could appear to be disparate approaches of individual studies. However, as the primary focus of Low et al. (2019) was to develop a framework to describe previous analytical approaches, there was limited synthesis and evaluation of the applicability of the evidence base. Given the complexity of spatial-temporal metrics and non-linear analysis approaches in comparison to conventional performance analysis methods, there is a need for authors' to effectively describe metrics and analysis approaches, providing context and recommendations so that practitioners and coaches can identify the value of the information and make appropriate decisions. In addition, effective discussion of validity and reliability of different metrics and analysis approaches would further enhance the practical

value of the research. Therefore, the purpose of this current systematic review was to synthesise and evaluate the applicability of research investigating spatial-temporal metrics to analyse collective behaviours in football. The review identified and evaluated authors' descriptions of metrics and clarity provided to facilitate uptake by practitioners. A similar process was included with authors' discussions of practical applications of study findings. Finally, evaluations of research quality and attempts to address validity and reliability of approaches in primary studies were also included.

## Method

A systematic review of published studies investigating spatial-temporal metrics for collective behaviour in football was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA). An initial scoping review of the research base was conducted to familiarise authors with the key metrics used and generate appropriate keyword searches. Subsequently, five electronic databases including SportDiscuss, Embase, Medline, Web of Science, and Scopus were searched and considered publications from the 1st of January 2008 to the 20th of February 2019. The search strategy combined two levels, the first included the following terms combined with the Boolean operator OR: 'centroid', 'centre of gravity', 'stretch index', 'team spread', 'surface area', 'dominant region', 'approximate entropy', 'relative phase', 'dyad', 'voronoi', 'coordination', 'patterns of play', 'performance analysis', 'tactical analysis', 'notational analysis', 'group behaviour', 'group behavior', 'collective behaviour', 'collection behavior'. Results from the first level were then combined using the AND operator with the second level comprising: 'football' OR 'soccer'.

Inclusion criteria for retrieved studies included: 1) participants of any age or sex engaging in football competition or training; 2) reporting of spatial-temporal metrics comprising at least two position references that described collective behaviour; and 3) the full publication was available in English. Investigations published as conference abstracts were excluded. Two separate reviewers (MC and NB) screened article titles then abstracts. Full-texts were then read and inclusion criteria applied to complete the 3-stage screening process. Disagreements regarding inclusion were resolved with discussion at the end of the

abstract and full-text stages. The primary purpose of the review was to synthesise and evaluate the included research by considering authors' descriptions of metrics and their discussion of reliability, validity, and practical application of findings. Therefore, data extraction was completed using two different extraction forms. The first extraction included basic information such as population investigated, sample size, specific metrics applied, analysis approach and overarching findings. The individual metrics and analysis approaches that were identified were categorised according to the criteria identified by Low et al. (2019). The second extraction included information regarding authors' descriptions of included metrics and comments regarding their validity, reliability and practical applications. Direct quotes were extracted from each study and where multiple appropriate quotes were present, all were documented. Quotes regarding practical applications were categorised as either: 1) broad - generic conclusions providing limited direct applicability; 2) moderate – conclusions linked to specific game or training aspects providing some direct applicability; 3) specific – clear recommendations with specific reference to the use of a metric or analysis method providing direct applicability. Extractions were conducted independently by two reviewers (MC and TC) with a final discussion including the categorisation of the application of metrics amongst the full research team to ensure consistency.

To evaluate the methodological quality of studies a risk-of-bias quality form was adopted based on a 12-item checklist adjusted from Sarmento et al. (2018b). Studies were assessed based on the following criteria: 1) study purpose; 2) background literature; 3) study design; 4) detail of sample used; 5) justification of sample size; 6) identification of ethical approval; 7) detail of methods; 8) application of appropriate inferential statistics; 9) application of relevant analysis

methods; 10) generation of appropriate conclusions; 11) generation of appropriate practical applications; and 12) acknowledgement of study limitations. A binary scale was used to score each item with the percentage of positive items awarded a unit score to provide an overall quality rating. Three bins were created to group articles into low (≤50%), moderate (>50%, ≤75%), and high (>75%) quality (Sarmento et al. 2018b). Data extraction and risk of bias assessment were made in duplicate across three reviewers (MC, NB and TC) with a final discussion amongst the full research team.

## Results

The initial literature search identified 2282 studies which was reduced to 1110 after deduplication. Title and abstract screening reduced the number of studies obtained in full-text to 97. A further 12 studies were removed due to metrics not meeting the inclusion criteria specified (7), non-reporting of data (3), and inclusion of sports other than football (2). The 85 included studies comprised a wide range of population groups (Table 1) with respect to game type (competition, friendly, training game, small sided games (SSGs) and 1v1 bouts), playing level (professional, youth, semi-professional, amateur, composite), and country of investigation (Australia, Austria, Brazil, England, Finland, Germany, Italy, Multi-national, Netherlands, Portugal, Spain and Switzerland). The mean number of matches analysed was 10.6 with a standard deviation of 18.1 (range: 1 to 103). Thirty-one studies investigated metrics across full 90-minute matches, whereas most studies investigated much shorter SSGs. Findings from the studies were varied (Supplemental) and generally focused on relation of metrics to success in terms of offense or defence, or the effect of factors such as gender, age, formations, tactics, number of players or pitch dimension on metric values.

The research quality evaluation (Table 2) identified a single (1.2%) "low quality" study, 30 "moderate quality" studies (35.3%) and 54 "high quality" studies (63.5%). The studies were most susceptible to bias through a lack of sample justification with only 5 studies (5.9%) stating a reason for the population selected. The research quality evaluation also highlighted that most studies failed to acknowledge study limitations (62.7%) and many (21.9%) failed to identify practical applications. Where studies did identify practical applications, these were

most often categorised as being broad and providing limited clear applicability (54.0%; Table 3). Examples of practical applications categorised as being of moderate applicability (36.8%) generally focused on constraints that could be applied in training including manipulation of pitch size (Goncalves et al. 2018a) formations (Baptista et al. 2018) and SSGs (Praça, Folgado, De Andrade & Greco 2016; Goncalves et al. 2017). A limited number of practical applications (9.2%) were categorised as specific and provided clear recommendations with target values for team centroid (Aguiar, Goncalves, Botelho, Duarte & Sampaio. 2015), field space (De Souza 2018, Goncalves et al. 2018b) and distance between players (Headrick et al. 2012) that could be directly applied by practitioners and coaches.

Across the 85 studies, 115 unique metrics and analysis approaches were identified across a total sample of 366. A total of 84 (23%) instances were identified where an equation was presented. In contrast, there were 99 (36%) instances where a metric or analysis procedure was reported with no equation or source provided to describe calculations. Similarly, there were 79 (21%) instances of metrics reported with no formal description or comment to provide context or understanding of the purpose of the metric. According to the framework presented by Low et al (2019), the most commonly reported metric category was space metrics (129 instances), followed by distance metrics (110 instances), position metrics (21 instances) and technical-tactical metrics (17 instances). Non-linear analysis methods quantifying synchronisation (52 instances) were most frequently applied using the Hilbert transform and at the team level through assessment of team centroids to identify coordinated movement across teams (Gonçalves et al. 2014, Siegle & Lames 2013). Predictability analysis methods (37 instances) were

most frequently applied using approximate entropy (ApEn), followed by sample entropy (SampEn) and Shannon entropy.

No explicit reference was made to reliability or validity of metrics in any of the included studies. Implicitly, authors assessed the validity of metrics through multiple approaches. The most common was to employ rank-order methods and compare metrics across age groups or playing levels with the implicit assumption that older players and those playing at a higher level or in stronger teams would demonstrate more effective collective behaviours. Barnabe, Volossovitch, Duarte, Ferreira & Davids (2016), Castallano et al. (2017), Olthof, Frencken & Lemmink (2015), Palucci et al. (2018) each identified positive relationships between metrics and age with greater width, surface area, team spread, team centroid distance and attack-defence synchronisation with older players. Similarly, Silva et al. (2014a) identified that players of the same age group but from a higher standard of competition worked together more effectively to explore greater amounts of available space. Additionally, Folgado Duarte, Fernandes & Sampaio (2014) identified that competition against stronger teams resulted in increased time in synchronized behaviour for overall displacements and displacements at higher intensities.

## Discussion

The present study comprised a systematic review of research investigating collective behaviour in football through analysis of spatial-temporal data. The review identified that the area is rapidly growing and features a wide range of metrics (spaces, distances, positions and numerical relations), analysis methods (synchronisation and predictability), populations (primarily elite level males from U11 to adult) and game scenarios (e.g. competitive matches, SSGs, and 1v1 drills). Focus of the review was placed on authors' descriptions of the metrics generated and their discussion of reliability, validity, and practical applications of findings. The present review identified several areas for further development of the evidence base to increase the quality of the information and uptake in practice. An initial barrier was identified with regards to authors' descriptions of metrics with overemphasis placed on operationalised definitions and limited translation to game scenarios or coaching strategies. Additionally, when discussing practical applications, it was identified that authors frequently provided broad statements that restated results and did not provide clear recommendations with guidelines on relevant values or processes that could be used to generate team specific values. The following sections discuss in greater detail the data extracted from the review.

For practitioners to assess and apply a metric and analysis approach to their own data, an understanding of what the approach measures and how it relates to performance is required. However, review of the included studies identified that most authors' descriptions lacked conceptual overview, and instead focused exclusively on operationalised definitions. Common examples across the metric

categories included: Spaces (surface area): "the convex hull formed by positions of the players in each team" (Castellano et al. 2017); Distance (distance between centroids): "the difference, longitudinally and laterally, between teams centroid positions" Frencken, De Poel, Visscher & Lemmink (2012); Position (relative angle): "the relative angle (α) between the centre of goal, defender and attacker" (Laakso, Davids, Liukkonen & Travassos 2017); and Numerical relations (Space Control Gain): "measured by the difference of space control percentage between pass initiation and pass completion modelled by utilising voronoi diagrams of the pitch at each time frame" (Memmert, Raabe, Schwab & Rein 2019). Similarly, descriptions regarding the two main analysis methods provided limited conceptual understanding with representative examples including: Synchronisation (relative phase): "the relative phase of the time series corresponding to speed displacements of all dyads" (Goncalves et al. 2018b); and Predictability (ApEn): "measure was used to assess the complexity of the particular collective behaviours" (Duarte et al. 2013a). In contrast, there were a limited number of examples where metric descriptions also provided conceptual detail to relate to aspects of football: "The stretch index measures the compactness of a team on a given moment" (Clemente, Sequieros, Correia, Silva & Lourenco Martins 2018); "[effective playing space] was calculated as the surface area of the convex hull of all players (excluding goalkeepers) as a measure of the playing area used by the players in a given situation" (Memmert et al. 2019) ; "[surface area] This variable expresses the relationship between the tactical forms (shapes) adopted and spaces exploited by both teams, to support analysis of how they varied over time" (Barnabe et al. 2016). In addition, primarily for numerical relations metrics there were examples where authors attempted to add context with regards to tactics and philosophy: "[offensive space ratio] The aim of this principle is to reduce the

concentration of opponents in their central zone, thus attempting to open up some spaces to penetrate" (Clemente, Martins, Couceiro, Mendes & Figueiredo 2014a); "[pressure passing efficacy] aims to measure high quality through-balls by weighing passes with more than one outplayed opponent by the pressure on both pass initiator and receiver" (Memmert et al. 2019). Whilst operational definitions and associated equations are important to ensure consistency across analyses, authors should seek to combine this information with greater context as demonstrated by these latter examples.

The review of included studies identified no explicit reference to reliability or validity of metrics and analysis approaches generated. Several authors referred to the reliability of instrumentation used to collect position measures (Castellano et al. 2017, Laakso et al. 2017, Praça et al. 2016); however, no study investigated the extent to which noise in data influenced reliability or consistency of values generated within for example single sessions (where tactics may be expected to be somewhat consistent). Metrics and analysis approaches that are unduly influenced by noise or vary substantially across time periods where collective behaviours are expected to be consistent should not be recommended. Across the included studies a wide range of systems measuring position coordinates were identified with variation in accuracy expected. As a result, future research should seek to identify the positional accuracy required to generate reliable data across different metrics and analysis approaches to inform practice and measurement systems used.

Whilst no explicit references were made in the included studies to validity, implicit attempts to assess validity were made using rank order methods to compare for example metrics across age groups (Barnabe et al. 2016; Folgado Duarte, Fernandes & Sampaio 2014; Olthof et al. 2015; Palucci et al. 2018) with the reasonable assumption that older players would demonstrate more effective collective behaviours. For example, Barnabe et al. (2016) identified significant differences in the surface area between U16, U17, and U19 teams. Similarly, Olthof et al. (2015) found significant differences in U17 and U19s lateral stretch index. However, for collective behaviour approaches to be more widely used by practitioners there is need for future research to establish the sensitivity of approaches to distinguish between strong and weak teams within leagues or distinguish between good and bad performances within a single team.

In addition to rank order methods, included studies also implicitly investigated validity by assessing whether approaches to assessing collective behaviour demonstrated longitudinal patterns that would be expected with regards to fatigue or increased experience. Goncalves et al. (2018a) observed the variation in teammate dyad synchronisation over 51 matches. Synchronisation of players increased when walking and decreased when jogging and running as the match progressed. Moreover, coefficient of variation values identified greater variation in jogging and running synchronisation as matches progressed which the authors attributed to mental fatigue. In the context of increased experience, Folgado, Duarte, Fernandes & Sampaio (2018) investigated synchronous behaviours of a professional football team from the beginning of pre-season to the end of pre-season during 9v9 matches. Analyses identified an increase in synchronisation between the first and last training sessions consistent with the hypothesis that

familiarity and greater synchronised behaviours can emerge as team-mates obtain greater experience playing with each other. These and similar results generated highlight that tempo-spatial metrics may be sensitive to a range of external factors relevant to football. However, the results also highlight potential variability in metrics within and between games, which may have to be accounted for by practitioners when profiling data obtained.

A limited number of the studies included in this review also attempted to assess whether spatial-temporal metrics could predict critical events. Moura et al. (2016) applied vector coding to team spread and identified differences between inter-team coordination preceding shots on goal, and defensive tackles. The authors reported that attacking plays that ended in shots on goal presented greater anti-phase patterns in the early stage of the possession and that teams should attempt to present contrary behaviours to their opponent as soon as ball possession is regained. In a more focused aspect of game play, Shafizadeh, Davids, Wheat & Hizan (2016) analysed 1v1 situations between strikers and goalkeepers in the English premier league. Results demonstrated that interpersonal distance and relative velocity between attacker and goalkeeper in the longitudinal direction influenced the probability of a goal being scored or not. Whist these findings and others may provide initial information regarding collective behaviours preceding important events, a challenge for researchers and practitioners is to determine what football related strategies should be employed when limitations are identified. Given the complexity of sport such as football where multiple confounding factors limit clear explanations (Carpita, Sandri, Simonetto & Zuccolotto 2016), development in this area may require greater integration

between metrics and football strategies or identification of key constraints that can be manipulated to alter behaviours.

Based on recognition that collective behaviour analyses must ultimately provide practitioners with information to improve performance through adaptations to training design or match play (Memmert 2017, Sarmento et al. 2018a), clear discussion of practical applications of findings from research is required. Review of the included studies identified that a substantive portion (21.9%) did not make any direct reference to practical applications. Additionally, it was identified that when practical applications were made by authors these were most often broad, reiterating results of the study in slightly different contexts that demonstrated limited actionable qualities. Representative examples of broad practical applications (Table 3) included: "Varying individual playing area by manipulating number of players or by manipulating pitch dimension possesses different implications on emergent teams' behavioural patterns. Therefore, this evidence is an important aspect for coaches to consider" (Chung, Carvalho, Casanova & Silva 2019); "The results of this study can provide valuable tools for controlling player organisation on the pitch" (Moura et al. 2013); "The manipulation of informational constraints to shape tactical behaviour may be an asset" (Silva, Vilar, Davids, Araujo & Garganta 2016); "The phase couplings and other spatial-temporal relations among players and teams reflects their tactical performances and should consequently be considered by coaches in the design and implementation of small-sided games." (Travassos, Vilar, Araujo & McGarry 2014). Collectively, examples of broad practical applications identified to practitioners and coaches procedures that may have potential to improve collective behaviours but provided limited information to enact changes in training or competition. Additionally, when

combined with metrics and analysis procedures that are not well contextualised with regards to football specific actions or well understood tactics, broad practical applications made by researchers are unlikely to be implemented.

The next most common categorisation of practical applications was moderate where authors linked conclusions to specific aspects of competitive games or training drills. Consistent with the dynamic systems approach, many practical applications categorised as moderate focused on different types of constraints as a means of altering collective behaviours. Examples of manipulating organismic constraints were proposed by Folgado, Bravo, Pereira & Sampaio (2018) and Figueira, Goncalves, Masiulis & Sampaio (2018) who recommended altering team make up of stronger and weak opponents in training, with drills featuring stronger opponents tending to increase synchronisation. In contrast, Coutinho et al. (2019b) identified that manipulating environmental constraints in the form of spatial references with additional pitch lines altered collective behaviours. Inclusion of reference lines was found to increase team defensive behaviour with lower approximate entropy values and was recommended for situations where more structured patterns of play were desired (Coutinho et al. 2019b). In contrast, removal of reference lines was found to increase players' movement synchronisation which was recommended for developing offensive movement patterns through lower structured playing styles to create instabilities (Coutinho et al. 2019b). Finally, multiple authors identified task constraints that were categorised as moderate practical applications focusing on SSGs. Manipulations of formations (Baptista et al. 2018) and overload situations (Praça et al. 2016, Goncalves et al. 2017) were identified as strategies to enhance both effective attacking and defensive behaviours. Whilst practical applications identified as

moderate provide coaches and practitioners with clearer guidance on potential constraints to manipulate and analysis procedures to adopt, the examples did not provide guidance on values expected and what may represent substantive changes. One of the most consistent conclusions across the research base was that greater synchronisation in spatial-temporal metrics tended to reflect more effective behaviours (Clemente, Santos-Couceiro, Lourenco-Martins, Sousa & Figueiredo 2014; Clemente, Couceiro, Martins, Mendes & Figueiredo 2014; Coutinho et al. 2019; Folgado Duarte, Fernandes & Sampaio 2014; Folgado, Duarte, Fernandes & Sampaio 2018; Goncalves et al. 2017). However, recommendations and guidance identifying expected changes in values for different metrics may be required to facilitate greater uptake in practice.

In a small number of instances, it was identified that authors provided specific practical applications that included recommendations of metric values that were linked to relevant training situations and goals. Aguiar et al (2015) recommend that players should be approximately 5-6m from their team centroid during 3-a side SSGs to enhance availability of environmental cues and ability to pass effectively. Similarly, Gonclaves et al. (2018a) recommended that players adopt approximately 12 $m^2$ effective playing space for actions involving three team mates to enhance availability of environmental cues and control players' positioning while defending. Additionally, multiple authors provided specific recommendations regarding pitch dimensions to enhance collective behaviours described by distances and positional measures in youths (Castellano et al. 2017) and female (Zubillaga) players. In contrast to researchers providing specific recommendations regarding metric values, it has been suggested that practitioners and coaches set their own values based on their philosophy and

tactical approach to matches (Clemente, Couceiro, Martins, Mendes & Figuieredo 2013). Additionally, it is recognised that given the extent to which the spatial-temporal research base is developing with novel metrics and analysis approaches that many studies are explorative and clear practical applications should not be expected. However, transfer of the approaches from the research domain to practical use will require more specific recommendations linked to football specific concepts, or clearer guidance on procedures that can be used by coaches and practitioners to develop their own values and monitoring processes.

Based on the risk of bias assessment, one of the key weakness in the included studies was authors' lack of justifying sample size, with only 5.9% of studies providing justification. The number of matches investigated in the included studies ranged from 1 to 103. Most studies investigated fewer than 10 matches, with similar metrics used for both analysis of 11v11 matches and SSGs. These findings suggest that most studies feature convenience samples rather than identifying likely effect magnitudes and performing analyses to identify sample sizes required to obtain appropriate statistical power. Alternatively, considerations could be made on the data an individual team might have available and justify the sample by grounding the research in a practical context. Broader consideration of populations investigated in the research identified a substantial skew towards male players, with only two studies incorporating females (Tenga, Zubilaga, Caro & Fradua 2015, Zubillaga et al. 2013). It is unclear whether collective behaviour as assessed by spatial-temporal metrics would be different between males and females. Tenga et al. (2015) identified similarities between the playing length and width of both male and female players. However, male players demonstrated higher levels of variation which was suggested to aid in creation of more space

and passing opportunities. Further analysis should be conducted to identify clearer differences across a range of metrics between males and females. If clear differences are identified then further investigation in collect behaviour in women's football must be executed to provide gender disaggregated data.

A key area for future investigation that may assist with practitioners adopting assessment of collective behaviours includes addressing the link between competitive matches and training. Matches provide information on team dynamics within the performance context, however, official competitions are relatively fixed, whereas during training sessions, coaches are free to make large changes to constraints in attempts to alter behaviours and generate effective team dynamics. The information obtained during training sessions could then be used to inform strategies during matches and determine whether similar changes to team dynamics emerge. To date, studies have identified that subtle differences in collective behaviour metrics can be obtained by manipulating constraints such as pitch dimensions, number of players and player formations (Aguiar et al. 2015, Castellano, Silva, Usabiaga & Barreira 2016, Castellano et al. 2017, Coutinho et al. 2019b, Frencken, Van der Plaats, Visscher & Lemmink. 2013, Olthof, Frencken & Lemmink. 2019a, Praça et al. 2016, Silva et al. 2014b, Travassos, Goncalves, Marcelino, Monteiro & Sampaio 2014). However, due to the lack of understanding of ideal values for metrics, it is unclear whether these adaptations are desirable. Moreover, understanding how these manipulations translate from training into matches is a further abstraction that at present there is no evidence for.

## Conclusions

There has been a substantial increase in the number of studies investigating collective behaviours using positional data in football over the last decade. Only 23 studies matching these criteria were identified between 2008 to 2013, whereas 62 studies were identified between 2014 to 2019. Additionally, more recent studies have more frequently included numerical relations (16/17), synchronisation (45/52) and predictability (32/37) metrics than studies prior to 2014. Across the included studies many metrics were analysed using a range of approaches producing extensive areas for future research and practitioners to implement. Whilst the research base highlights that collective behaviour analysis through spatial-temporal data may provide unique insights into performance in football, there are limitations and gaps in understanding that currently prevent the widespread use of the approaches in practice. Common limitations acting as barriers to implementation include reliance on purely mathematical descriptions of metrics at the expense of clear conceptual descriptions. Similarly, a lack of detailed practical applications including normative data and clear guidance on how player position and relative movement are best manipulated to simultaneously improve metric values and performance currently limits uptake. Greater conceptual clarity of metrics may be obtained by researchers incorporating the views and playing principles of coaches to align or adjust metrics. This process may enhance coach buy-in and as a result the likelihood of performance analysts conducting collective behaviour analyses as part of their reporting to coaches. In contrast, progressing to the stage where clear practical recommendations can be made is likely to require substantially more research. Important aspects for future research to consider include the assessment of reliability; establishing whether collective behaviour metrics are sensitive enough to explain performance

differences between teams and stronger performances within a team; and whether manipulations in training can create changes in collective behaviours and their associated metrics that transfer to competition.

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Table 1: Summary of study characteristics

| Classification | Population type | Frequency |
|---|---|---|
| **Game type** | Official competition | 30 |
| | Friendly | 3 |
| | Training Game | 9 |
| | Small-sided conditioned game | 37 |
| | 1v1 bouts | 6 |
| **Playing level** | Professional | 33 |
| | Youth | 38 |
| | Semi-professional | 2 |
| | Amateur | 9 |
| | Composite | 3 |
| **Country observed** | Australia | 1 |
| | Austria | 1 |
| | Brazil | 8 |
| | England | 7 |
| | Finland | 1 |
| | Germany | 2 |
| | Italy | 1 |
| | Multi-national | 4 |
| | Netherlands | 4 |
| | Portugal | 18 |
| | Spain | 8 |
| | Switzerland | 1 |
| | Unspecified | 29 |

**Table 2:** Research quality evaluation.

| Quality Item | Success rate |
|---|---|
| A clearly stated study purpose | 100% |
| Relevant background literature used | 100% |
| Appropriate design for the research question | 98.80% |
| Detailed reporting of the sample size | 96.50% |
| Justification of the sample size | 5.90% |
| Informed consent or ethical permission | 87.10% |
| Detailed reporting of methodology | 97.60% |
| Used inferential statistics related to the aim | 89.40% |
| Appropriate analysis methods considering the study aim | 94.10% |
| Appropriate conclusions stated relating to study methods | 96.50% |
| Stated practical applications derived from study results | 63.50% |
| Acknowledged and described study limitations | 37.70% |

Table 3: Summary of practical applications identified in included studies

| Application type | Author | Year | Representative quotes |
|---|---|---|---|
| **Broad** (generic conclusions providing limited direct applicability) | Chung | 2019 | "this evidence is an important aspect for coaches to consider when planning SSCG tasks, since manipulation of [individual playing area] through different constraints manipulation (i.e., pitch dimension or number of players) promote different contextual information as well as new affordances. |
| | Clemente | 2014c | "players should be repositioned to ensure the in-phase relationship and adjust the distance between the centroids." |
| | Coutinho | 2019a | "using different pitch configurations might help players to improve their ability to identify the most relevant cues that support the emergence of functional behaviours." |
| | Frencken | 2013 | "Coaches must carefully choose the type of small-sided game in training, as interaction patterns vary depending on pitch dimensions." |
| | Goncalves | 2018b | "Coaches should prepare physical and mental fatiguing practice tasks to increase players ability to adapt and perform under these scenarios." |
| | Moura | 2012 | "Automatic tracking methods during training sessions allow coaches to calculate the same variables proposed in the present research, and based on this information, they can precisely control their players' organisation on the pitch and systematise tactical strategies." |
| **Moderate** (conclusions linked to specific game or training aspects providing some direct applicability) | Castellano | 2013 | "The surface area may help to explain the defending flow" |
| | Clemente | 2015 | "can be useful information to coaches in order to control the superiority or inferiority zones, reorganizing a team's strategies according to its weaknesses or strengths |

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| | Clemente | 2013b | "the speed and angular positioning of the attacker are key factors when trying to unbalance the attacker-defender dyad." |
| | Folgado | 2014a | "Selecting stronger opponents for matches during the pre-season seems to promote more synchronized behaviors between players." |
| | Siegle | 2013 | "perturbations can be used to identify playing situations in which one team attacked in a way, which the defending team was not able to answer." |
| | Vilar | 2013 | "This method captures how teams explored different regions to maintain backward stability and create forward instability, in accordance with the shape and location of the area of play." |
| **Specific** (clear recommendations with specific reference to the use of a metric or analysis method providing direct applicability) | Aguiar | 2015 | "For example, in a 3-a side SSG, these distances [player to team centroid] should be around 5 to 6 m and, therefore, require the optimisation from the focus on environmental cues, passing performances and explosive strength and power within these limits." |
| | De Souza | 2018 | "As for practical recommendations of our paper, coaches may create, for instance, 6 × 6 SSGs with the spaces presented in the study: about 23 m in length and 44 m in width, with the objective of motivating players to invade the space." |
| | Headrick | 2012 | "player-to-ball relationships can be used to design practice tasks by positioning the players and ball within critical distances of each other. For example, a practice game could be designed with a D-Ball distance of 2m, representing the range at which the stable state of D-Ball distance appeared in this study." |

Supplemental Table: Summary of study details, findings and applications.

| Author | Sample | Metrics/Analysis | Findings | Applications |
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| Aguiar, Goncalves, Botelho, Lemmink & Sampaio 2017 | N= 6 small sided games (5v5) with U19 Males | Distances (2)<br>Predictability (2) | Higher **ApEn** scores were related to short sequences of play suggesting higher irregularity. | - Longer sequences of play demonstrated higher regularity than short sequences of play.<br>- Intra-team interactions had comparatively higher regularity compared with inter-team interactions in short sequences, however the reverse was found in long sequences.<br>- Coaches should design game strategies to increase consistent intra-team or inter-team behaviours. |
| Aguiar, Goncalves, Botelho, Lemmink & Sampaio 2015 | N=24 small sided games (2v2/3v3/4v4/5v5) with U19 Males | Distances (3)<br>Predictability (1) | 4v4 and 5v5 small sided games resulted in collective behaviours that appeared more regular than 3v3 and 2v2 small sided games. | - For SSGs an increase in players [from 2 to 5] increases rational space occupation and players' positional regularity suggesting training tactical performance requires more players.<br>- For 3-a side SSG distance between players and team centroid should be 5 to 6 m. |
| Aquino et al. 2016a | N=4 matches of unspecified size with U16 males | Spaces (2) | A trend for increased **surface area** and **team spread** were observed from preseason phase to competition phase | - During pre-season, tactical performance should improve and can be measured by increases in size of surface area and team spread. |
| Aquino et al. 2016b | Single match unspecified size with U16 males | Spaces (2) | Significant increases in **team spread** and **surface area** were observed during 2nd half of matches. | - |
| Baptista et al 2020 | N=6 8v8 matches with semi-professional males | Spaces (4)<br>Distances (2)<br>Predictability (1) | Application of different formations (particular number of midfielders) significantly alter game dynamics. | - During 8-a-side matches the 4:3:0 formation can be used to increase the spread of players, conversely with the 4:1:2 formation which encourages compactness within the team. A 0:4:3 formation can be used to find balance between this concept of space exploration. |
| Barnabe, Volossovitch, Duarte, Ferreira & Davids 2016 | N=240 bouts of 6v6 with U16/U17/U19 males | Spaces (4)<br>Predictability (4) | Greater **width**, **surface area**, and **attack-defence synchronisation** were observed in older players when attacking. | - Older and more experienced players demonstrated more intricate attacking plays by demonstrating greater use of the width of the pitch and having a larger surface area.<br>- These values can guide coaches to adapt practice constraints to assist developing tactical behaviours in young players.<br>- Coaches and sport scientists can manipulate constraints in matches to improve player organisation specific to age group. |

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| Bartlett, Button, Robins, Dutt-Mazunder & Kennedy 2012 | N=10 11v11 matches with professional males | Spaces (4)<br>Distances (2) | Opposition **centroids** appear **synchronised** throughout matches. Clearer coordination patterns are obtained in the longitudinal direction. | - Team centroid metrics and dispersion metrics including surface area, team spread and stretch index do not appear to be sensitive enough for appropriate analysis of soccer team's performance. |
| Castellano, Alvarez, Figueira, Coutinho & Sampaio 2013 | N=6 11v11 matches with professional males | Spaces (1)<br>Predictability (1) | Regularity was observed in teams tactical strategies in attack and defence. | - When playing stronger teams, team length was measured between 40–55m describing direct attacks whereas against weaker teams more elaborate attacks were formed through smaller lengths of 25-40m. Coaches can use this information to develop effective tasks to develop players. |
| Castellano, Fernandez, Echeazarra, Barreira & Garganta 2017 | N=8 7v7 matches with U13/U14 males | Spaces (8)<br>Distances (1)<br>Predictability (1) | **Surface area** and **stretch index** can be increased by creating longer pitches. Distance between **team centroids** were greater in U13 compared with U14. | - Setting up a 60m length pitch for U14 male players can demonstrate similar team dynamics than elite professionals. |
| Castellano, Silva, Usabiaga & Barreira 2016 | N=6 6v6 matches with amateur males | Spaces (3)<br>Distances (1) | Coaches can manipulate constraints to achieve desired player behaviour in training sessions. | - |
| Chung, Carvalho, Casanova & Silva 2019 | N=6 3v3, 4v4, 5v5 matches with Under 15 males | Spaces (2) | Manipulating the number of players in each team can impact the **length** and **width** during small sided games. | - Coaches should consider manipulating the individual playing area by altering field dimension or number of players in a match to achieve the desired co-adaptations. |
| Clemente, Couceiro, Lourenco Martins, Dias, Mendes, 2013 | N=30 bouts of 1v1 with U18 males | Distances (1)<br>Positions (2) | In 1v1 situations, **speed** and **angular position** of attacker relative to defender are critical to success. | - Increases in speed and angular variation are required to unbalance an attacker defender dyad to help create scoring opportunities in 1v1 situations.<br>- Coaches can provide instructions to constrain players decision making processes and alter co-adaptive behaviours. |
| Clemente, Couceiro, Lourenco Martins, | Single 7v7 match with U13 males | Numerical relations(1)<br>Predictability (1) | There are high levels of variability in the centre of the field when observing **numerical advantage**. | - Defending teams should have more players in the central zone in the defensive area to secure that area and make it tougher for opponents to score. |

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| Mendes & Figueiredo 2015 | | | | - High levels of variability in the central areas of the park are used to destabilise the opponents to create goal scoring opportunities. |
| Clemente, Couceiro, Martins, Mendes & Figueiredo 2013a | N=3 11v11 matches with professional males | Spaces (3)<br>Distances (1) | Fatigue influences collective organisation and causes **surface area** and **stretch index** to decrease in 2nd half. | - Higher values in surface area, stretch index and effective area of play can potentially be linked with better performance as it suggested lower values are found in phases where teams have become fatigued.<br>- Coaches should monitor these values in regular training practices and adapt tasks to manifest effective behavioural habits. |
| Clemente, Couceiro, Martins, Mendes & Figueiredo 2013b | Single 7v7 match with U13 males | Spaces (2)<br>Distances (2) | Attacking teams attempt to expand **effective play area**, whereas, defending teams look to decrease the metric. | - Metrics such as surface area and stretch index can indicate how expansive or contracted teams want to be in certain situations. Coaches should set their own limits for these aspects and other measurable factors such as optimal distance in defence triangulations based on their own philosophy. |
| Clemente, Couceiro, Martins, Mendes & Figueiredo 2014 | N=3 11v11 matches with professional males | Spaces (3)<br>Positions (1) | **Weighted stretch index** and **surface area** are greater when teams are losing. | - Coaches can improve synchronisation of the team by observing variables including team centroid, dispersion and triangulations formed.<br>- Opponent coaches can observe this data to identify strengths and weaknesses and adjust team tactics to exploit certain behaviours. |
| Clemente, Couceiro, Martins & Mendes 2013 | Single 7v7 match with U13 males | Spaces (2)<br>Distances (3) | An inverse relationship exists between opposing team's **effective area of play**. | - Effective area of play can be used to measure team contraction and expansion and a system can be created to provide online feedback to coaches to quantify these principles. |
| Clemente, Couceiro & Martins 2012 | Single 7v7 match with U13 males | Spaces (1) | Metrics quantifying collective behaviours can be generated live and used to improve decision making during training sessions. | - A visualisation strategy can be used to help coaches understand tactical changes in the team's behaviour.<br>-The coach can use this information to manipulate the players behaviour in real time. |
| Clemente, Martins, Couceiro, Mendes & Figueirido 2014a | N=3 11v11 matches with professional males | Numerical relations(3) | Novel variables including **penetration ratio, offensive space ratio** and **unity ratio** were associated with offensive success. | - These novel variables have potential to provide real time information to coaches and augment their perception of the game.<br>- Further improvements in augmented reality could provide improved visualisation techniques for coaches and players to learn from. |

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| Clemente, Martins, Couceiro Mendes & Figueirido 2014b | N=3 11v11 matches with professional males | Numerical relations(4) | novel metrics of **Cover in vigilance** and **Depth mobility** demonstrated high regularity and success | - Cover in support or in vigilance occurred at a mean ratio of 0.78, which are suggested as important principles of play in football.<br>- Coaches can measure the regularity of teams performing cover during training sessions and matches and additionally alter sessions to improve playing principles. |
| Clemente, Martins, Couceiro, Mendes & Figueiredo 2016 | N=3 11v11 matches with professional males | Spaces (4) | Novel metrics such as **defensive play area** which can be used to describe the organisation of the defence in different areas on the pitch | - Higher number of defensive triangulations in the midfield area are associated with positive match results. |
| Clemente et al. 2018 | N=2 11v11 30 min matches with amateur males | Spaces (1) | Use of full size pitch emphasises mobility, whereas, half-pitch emphasises teams working as a unit. | - Using a half-sized pitch can result in an increase of space exploration by players on the pitch. This information can be sent on to a coach mid game and help inform the coach in their decision making processes. |
| Clemente, Santos-Couceiro, Lourenco-Martins, Sousa & Figueiredo 2014 | Single 11v11 match with professional males | Distances (3) | Opposing **team centroids** were synchronised in lateral and longitudinal directions. Additionally, successful teams maintained greater **team centroid** distance in defence. | - By adjusting relationships there can be in an increase in metric synchronisation such as weighted team centroid which is stated as being desirable for improved performance.<br>- Variables can be used to measure tactical performance. |
| Clemente, Sequiros, Correia, Silva & Lourenco Martins 2018 | N=2 11v11 30 min matches with amateur males | Spaces (3)<br>Distances (2) | Alteration of pitch size has significant effects on decision making and collective organisation as a team. | - Full size pitches are recommended to be used as a means of developing the team tactical principle of mobility. |
| Coutinho et al. 2019a | N=16 6v6 matches with U13/U15 males | Spaces (1)<br>Synchronisation (2) | Player decision is influenced by pitch length. | - Functional behaviours such as better positional decisions might be best developed using varied pitch configurations. |
| Coutinho et al. 2019b | N=6 7v7 matches with U15 males | Spaces (1)<br>Distances (1)<br>Predictability (1)<br>Synchronisation (2) | Spatial references cause teams to organise themselves in more | - Spatial references can be used to improve the regularity of teams positioning which is suggested to help develop defensive organisation. |

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| | | | regular but less **synchronous** structures. | - Removal of spatial references can help increase the synchronised behaviour between players which is suggested to improve the attacking threat of teams. |
| De Souza et al. 2018 | N=4 11v11 matches with professional males | Spaces (2)<br>Distances (1)<br>Numerical relations(1) | Attacking sequences commonly involve the interaction of a large number of players. | - Guidelines for coaches creating 6v6 SSGs should lay out pitches with length 23m in length and 44m in width. This should motivate players to invade space. After an invasion the distance to the goal should be 33m. |
| Duarte et al. 2013a | Single 11v11 match with professional males | Synchronisation (1) | Both teams demonstrated high **synchrony** that had mutual influence over the others collective behaviour. | - |
| Duarte et al. 2012a | N=82 bouts of 1v1 with U13 males | Predictability (1)<br>Synchronisation (1) | Successful attackers demonstrated high **synchrony** during 1v1 situations with the defender. | - |
| Duarte et al 2012b | N=20 bouts of 3v3 with U13 males | Spaces (1)<br>Positions (1) | During goal scoring opportunities, the distance between **team centroids** decrease. | - |
| Duarte et al. 2013b | Single 11v11 match with professional males | Spaces (4)<br>Positions (1)<br>Predictability (1) | **Approximate entropy** identifies that teams become more predictable and stable as a match progresses | **-** |
| Figueira, Goncalves, Masiulis & Sampaio 2018 | N=3 training matches 11v11 with U15 and U17 males | Distances (1)<br>Predictability (1)<br>Synchronisation (1) | Movement **synchronisation** was different between age groups | - Mixing age groups, for example U15 and U17 can lead to potential improvements in performance through increased coordinated behaviours. |
| Filetti, Ruscello, D'ttavio &Fanelli 2017 | N=70 11v11 matches using professional males | Numerical relations(2) | Training should focus more on developing players decision making as opposed to physical fitness | - The technical efficiency index is a strong predictor of team performance and result and each individual player should be monitored to measure improvements in this index.<br>- If a team scores a technical efficiency index of >5 compared to their opponents the likelihood of winning is near 100%. |

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| Folgado, Bravo, Pereira & Sampaio 2018 | N=18 5v5 matches with U15 males | Spaces (2)<br>Distances (2)<br>Synchronisation (2) | Adapting the pitch width and length can be used by coaches to achieve desirable behaviours from players during training. | - |
| Folgado, Duarte, Fernandes & Sampaio 2014 | N=6 11v11 first half friendly match with professional males | Synchronisation (2) | Players demonstrate higher levels of **synchrony** with team mates when playing stronger opponents | - Playing against stronger opponents in training and in matches increases the synchronisation between teammates which is indicative of improved performance. |
| Folgado, Duarte, Marques, Goncalves & Sampaio 2018 | N=4 11v11 matches using professional males | Synchronisation (2) | **Synchronisation** is a potential performance indicator to analyse tactical performance | - Successful teams demonstrated higher levels of synchronised behaviour compared with losing teams during matches.<br>- An individual teams synchronisation values can me be measured across matches to provide understanding of team performance. |
| Folgado Duarte, Marques & Sampaio 2015 | N=6 11v11 matches with professional males | Synchronisation (2) | Congested fixture lists can cause a decrease in **synchrony** between team mates. | - The lower synchrony between team-mates during congested fixture lists can be used to identify players who should be rotated. Alternatively, specific training practices could be used to improve synchronised behaviours during congested fixtures. |
| Folgado, Goncalves & Sampaio 2018 | Unspecified number of 9v9 matches with professional males | Synchronisation (2) | Large sided games can be used to develop **synchronous** behaviours with new team mates during pre-season training. | - More experienced players develop synchronous behaviours quicker compared with less experienced players in meaningful training sessions.<br>- Coaches should monitor tactical development of their team during pre-season. |
| Folgado, Lemmink, Frencken & Sampaio 2014 | N=6 small sided games (4v4/5v5) with U9/U11/U13 males | Spaces (3)<br>Distances (1) | Applying different constraints to small sided games can influence metrics such as **centroid** and **length per width ratio**. | - |
| Frencken, De Poel, Visscher & lemmink 2012 | Single 11v11 match with professional males | Distances (6) | Variation in distance between **team centroids** is linked to critical events in a match. | - |
| Frencken, Lemmink, | N=3 5v5 matches with U19 males | Spaces (3)<br>Distances (3) | Movement of **team centroid** is associated with | - Overlapping centroids may have some bearing on identifying goal scoring opportunities and should be monitored by sports scientists to |

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| Delleman & Visscher 2011 | | | creation and scoring of goals. | provide the coach with appropriate tools to set more effective training tasks for the team. |
| Frencken, Van der Plaats, Visscher & Lemmink 2013 | N=4 5v5 matches with amateur males | Spaces (2)<br>Distances (2) | Altering pitch length and width in small sided games influences distance between **team centroids.** | - Coaches should carefully think about setting out SSGs as pitch dimensions can vary team interactions significantly. |
| Frias & Duarte 2014 | N=2 6v6 matches with U17 males | Spaces (3)<br>Distances (1) | Man-to-man marking system are more variable in dispersion metrics such as **surface area** and **stretch index** compared with teams that use zonal marking. | - Coaches instructing teams to use zonal marking as a defensive strategy should expect more compact surface area and stretch index, and less variability. Alternatively, a greater and more variable inter-team distance will also be present in the team dynamics. |
| Goncalves et al. 2019 | N=12 11v11 matches using professional males | Spaces (4) | Measuring spatial-temporal patterns can provide guidance for designing more effective training sessions | - An example base structure is provided involving a play area of length 36m and width 48m placed 18m from the goal from which training tasks can be designed around. |
| Goncalves et al 2018a | N=51 11v11 matches with professional males | Synchronisation (3) | Gradual decrease in **synchronisation** among players occurs throughout a match based potentially on fatigue. | - Coaches should prepare training practice which increase players' ability to perform under fatigue and mental fatigue |
| Goncalves et al. 2017 | N=2 11v10 matches with professional males | Distances (2)<br>Predictability (1)<br>Synchronisation (2) | Greater focus on tactics employed can be achieved when restricting playing areas for each player. | - Unrestricting player movement will increase the synchronisation between players in a team.<br>- Coaches are encouraged to increase the levels in synchronisation in a team. |
| Goncalves, Figueira, Macas & Sampaio 2014 | Single 11v11 50 min match with U19 males | Distances (9)<br>Predictability (9)<br>Synchronisation (6) | **Group centroids** based on position demonstrate high **synchrony**. Midfielders demonstrate the highest **synchrony**. | - |
| Goncalves et al. 2018b | N=6 11v11 first half matches with professional males | Spaces (1)<br>Predictability (1) | Variation identified in **effective playing space** suggests that coaches | - Field dimension will impact the environment cues from which players adapt and learn from. |

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| | | | should design practices carefully to focus on specific match scenarios. | - Approximately 12m$^2$ effective field space is stated as enhancing players perceptions for actions involving 3 teammates |
| Goncalves, Marcelino, Torres-Ronda, Torrents & Sampaio 2016 | N=24 overloaded small sided games (4v3/4v4/4v7) with amateur and professional males | Spaces (1)<br>Distances (3)<br>Predictability (1) | Training sessions that involve overloaded situations emphasise use of local information in the decision making process to develop organised behaviours. | - SSGs with unbalanced situations such as a 7v4 can help players develop organisation behaviours and help players learn defensive principles of play including concentration and balance. |
| Headrick et al. 2012 | N=144 bouts of 1v1 with U17 males | Distances (2) | During 1v1 situations, the proximity to goal influences decision making of both attacker and defender. | - During 1v1 bouts, practices should be designed with an intention of keeping the defender to ball distance at 2m which is stated as a critical distance which a stable state of the defender to ball distance appeared. |
| Laakso, Davids, Liukkonen & Travassos 2019 | N=142 trials of 2v1 with U15 males | Distances (1)<br>Positions (2) | Pitch location can constrain **interpersonal coordination** tendencies in 2v1 situations | - |
| Laasko, Travassos, Liukkonen & Davids 2017 | N=129 bouts of 1v1 with U15 males | Distances (1)<br>Positions (1) | Location on the pitch and favoured foot are constraints that can influence **interpersonal coordination.** | - Attackers and defenders can be provided practices on varying parts of the pitch to achieve specific behaviour developments to exploit space or nullify use of a stronger foot based on the position related to the goal. |
| Leser et al. 2019 | N=279 trials of 3v2 with U16 males | Distances (2)<br>Positions (2) | Sequences that were played wide and close to the goal line appeared to have more chance of resulting in a goal | - |
| Leser et al. 2015 | N=75 trials of 1v1 with U15 males | Distances (1)<br>Positions (2) | Spatial-temporal processes have a high potential in providing useful information to coaches | - The acceleration of an attacker when attempting to overcome a defender is the biggest indicator of success in a 1v1 bout, the higher the acceleration, the more likely a successful dribble will be completed. Therefore, coaches should attempt to improve this attribute in players attempting 1v1s. |

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| Lopez-Felip, Davis, Frank & Dixon 2019 | Single 11v11 friendly match using professional males | Distances (1)<br>Synchronisation (1) | **Distance to centroid** and **Synchrony** are both appropriate to be used when modelling the dynamics of a soccer match | - |
| Low et al 2018 | Single 10v11 training match using professional males | Spaces (2)<br>Distances (3)<br>Predictability (3)<br>Synchronisation (2) | Applying a high press strategy resulted in smaller **distances between opponent centroid** and higher regularity in **player distances to centroid** | - Coaches are recommended to use a high press strategy during matches where they have a numerical superiority as this will result in higher regularity in tactical patterns. |
| Memmert, raabe, Scwab & Rein 2017 | N=144 bouts of 11v11 with amateur males | Spaces (2)<br>Distances (1)<br>Numerical relations(2) | Changing formation in match like practices can influence metrics such as **length per width ratio**. | - The 3-5-2 formation demonstrated higher pressure passing efficiency which suggests a stronger through ball passing ability compared to a 4-2-3-1 which can help support decision making. |
| Menuchi, Moro, Ambrosio, Pariente & Araujo 2018 | N=4 4v1 possession games with U13/U15/U17/U19 males | Distances (5)<br>Positions (2) | The coupling of players during a rondo game are constrained by the age of participants and the spatial-temporal positioning of the participants | - The marking coupling can be influenced by the playing space of the rondo game. This can help coaches guide players to harmonious collective behaviours from their players. |
| Moura, Barreto Martins, Anido, Leite De Barros & Cunha 2012 | N=8 11v11 matches with professional males | Spaces (2) | Higher values of **team spread** and **surface area** were found in attacking teams compared to defending teams. | - |
| Moura et al. 2013 | N=10 11v11 matches with professional males | Spaces (2) | **Surface area** and **team spread** demonstrate a low frequency time series that decreased during the second half of matches. | - Surface area and team spread are valuable tools that can be observed and controlled by coaches in training and competition. |
| Moura et al. 2016 | N=10 11v11 matches with professional males | Spaces (1)<br>Synchronisation (1) | Teams that were slow to **synchronise** their **team spread** with their opponents were more | - Coaches should focus on aspects of play that occur directly after a transition.<br>- Higher levels of anti-phase and attacking team coordination in team spread were found directly after transitions, so coaches should seek to |

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| | | | likely to concede a goal scoring chance. | increase these values after winning the ball to improve likelihood of scoring. |
| Olthof, frencken & lemmink 2015 | N=24 5v5 matches with U17/U19 males | Spaces (3)<br>Distances (2) | Older age groups demonstrate greater **width** compared to younger age groups. | - |
| Olthof et al. 2019a | N=90 5v5 matches with U13/U15/U17/U19 males | Spaces (4)<br>Distances (2) | Playing space relative to match sizes influences the tactical performances with greater space to explore resulting in alternative collective behaviours. | - Match derived pitch areas might be an appropriate constraint to develop players in a representative learning environment. |
| Olthof et al. 2019b | N=20 11v11 matches 5 competitive, 15 training using U17 and U19 males | Spaces (6) | Training games demonstrate small tactical differences to competitive matches | - Coaches are recommended to use 11v11 matches in training to replicate as closely as possible the tactical behaviour of competitive matches. |
| Palucci Vieira et al. 2018. | N=12 11v11 matches with U11/U13/U15/U17/U20 and professional males | Spaces (2) | Older age groups demonstrate greater **surface area** and **team spread** compared to younger age groups. | - |
| Praca, Folgado, de Andrade & Greco 2016 | N=36 split evenly between 3v3, 4v3 and 3v3+2 with U17 males | Spaces (3)<br>Distances (1) | 3v3+2 small sided game resulted in a significant increase in width | - 3v3+2 SSGs appear to be useful for direct and counterattacking teams compared with the 4v3 condition which is recommended for teams who create chances through lateral movement. |
| Rein, Raabe & Memmert 2017 | N=103 11v11 matches with professional males | Spaces (1)<br>Numerical relations (2) | There appears to be a positive relation between team performance with **outplayed defenders** and **space dominance** | - An increase in space dominance or outplayed defenders could improve team performance in matches.<br>- Coaches can use these variables in preparation for matches as well as post-match analysis and feedback. |
| Ric, Torrents, Goncalves, Sampaio & Hristovski 2017 | Single 11v11 friendly match using professional males | Spaces (4)<br>Positions (2) | Measuring collective behaviour can help coaches observe if teams are developing over time | - |
| Sampaio, Lago, | N=28 5v5 matches with amateur males | Distances (1)<br>Predictability (1) | Variables such as match status and game speed can | - Coaches should manipulate game pace, match score and numerical superiority to achieve desired co-adaptive behaviours from their |

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| Goncalves, Macas, & leite 2014 | | | influence emergent team behaviour and situations involving overloads. | players and use measures such as distance of player to team centroid to evaluate team behaviour. |
| Sampaio & Macas 2012 | N=2 6v6 matches with amateur males | Distances (5)<br>Predictability (1)<br>Synchronisation (1) | Spatial-temporal data can be used as a collective to measure tactical patterns. | - More regular patterns of player distance to centroid when travelling slower than 13 km/h was identified as the biggest predictor after intervention suggesting this was indicative of better team tactical performance. Providing this information can improve the decision making of coaches. |
| Santos et al. 2018 | N=8 6v6 matches using U13 and U15 males | Distances (3)<br>Predictability (3) | A differential learning approach resulted in more regularity in players positioning | - Coaches apply differential learning variations in SSGs with young players to develop creative and tactically efficient behaviour. |
| Santos, Lagos-Penas & Garcia-Garcia 2017 | N=13 11v11 matches using professional males | Distances (2) | Changing match conditions results in players adapting their behaviour and decision making | - Coaches can set objectives for players in matches and practice sessions based on potential changes in the organisation of defending teams. |
| Serra-Olivares, Garcia Lopez & Goncalves 2019 | N=22 small sided games (7v7/8v8) using U11 and U12 males | Spaces (6)<br>Distances (6) | Older players were more able to organise themselves tactically to make use of the available space effectively | - Eight-a-side games are recommended for older and more experienced players while seven-a-side games are recommended for younger and less experienced players. |
| Shafizadeh, Davids, Correia, Wheat & Hizan 2016 | N=42 bouts of 1v1 with professional males | Positions (2) | Goalkeepers use informational constraints of **interpersonal distance** in 1v1 situations to intercept attackers. | - Learning goalkeepers and attackers should attempt to identify functional perception-action couplings in 1v1, task constraints can be manipulated to help with the learning process. |
| Siegle & Lames | Single 11v11 match with professional males | Synchronisation (4) | **Relative phase** analysis shows potential to identify valuable information during matches. | - |
| Silva et al. 2016 | N=13 11v11 30 min matches with amateur males | Synchronisation (3) | Synergistic behaviour is developed and enhanced through repeated practice. | - Higher levels of coordinated behaviour, both in phase and anti-phase are suggested to be increased to improve performance. |
| Silva et al 2014a | N=6 small sided games (5v5/5v4/5v3) using regional and national standard under 19 males | Spaces (2)<br>Distances (1)<br>Predictability (1)<br>Synchronisation (2) | National standard players adapt to constraints in small sided conditioned games differently to | - Field dimensions and other constraints can be intentionally manipulated by coaches to achieve desired team tactical organisation in training sessions to develop performance. |

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| | | | regional players. Identified that national standard players explore more of the available space. | |
| Silva et al 2014b | N=6 small sided games (5v5/5v4/5v3) with U19 males | Spaces (1)<br>Distances (5) | Small sided games can be constrained by overloads and conditions to manipulate player and team coordination. | - Numerical superiority is a constraint that coaches can manipulate to alter the behaviour and development of their team. |
| Silva, Vilar, Davids, Araujo, Garganta 2016 | N=3 small sided games (3v3/4v4/5v5) with U15 males | Spaces (3)<br>Distances (1)<br>Positions (2)<br>Synchronisation (2) | By altering the ratios of players in attack and defence, desired characteristics of play can be achieved through the space and time players have to make decisions. | - A time delay of 0.5s or more in centroid synchronisation could be enough to destabilise opponents and create dangerous opportunities. This information can be used by practitioners to adapt task constraints to achieve specific behavioural adaptations. |
| Steiner, Rauh, Rumo, Sonderegger & Seiler 2019 | N=5 11v11 first halves of matches using U18 males | Positions (1)<br>Numerical relations(1) | Positional data can augment the understanding of passing decision making | - understanding and evaluating situations in which riskier passes should and should not be made can be used to understand good and bad decision making of players at a deeper level. |
| Tenga, Zubilaga, Caro & Fradua 2015 | N=8 11v11 matches with males and females | Spaces (2) | There were key similarities in patterns of play in male and female matches. However, male patterns of play demonstrated greater variability. | - Tactical patterns from game specific structures can be used to develop collective tactical organisation by coaches. |
| Travassos, Goncalves, Marcelino, Monteiro & Sampaio 2014 | N=12 small sided games (5v5/5v4) with amateur males | Spaces (2)<br>Distance (1) | Small sided games with either equal or unequal numbers influence collective behaviours. | - Coaches should consider using relative phase couplings and other spatial-temporal measures such as surface area and team centroid when designing practices. |
| Travassos, Vilar, Araujo & McGarry | N=8 5v5 matches with professional males | Spaces (3)<br>Distances (3)<br>Synchronisation (8) | Increasing the number of goals in a conditioned game increases the distance between **team centroids** | - Using conditioned games with multiple small goals can increase the perception and breadth of attention from players altering their tactical performance. |

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| Vilar, Araujo, Davids & Bar-Yam 2013 | Single 11v11 match with professional males | Numerical relations(1)<br>Predictability (1) | **Numerical advantage** influences team stability/instability and collective behaviours that emerge. | - Practitioners can use numerical advantage to understand team performance quantitatively. |
| Zubilaga et al. 2013 | N=4 11v11 matches with semi-professional females | Spaces (3)<br>Distances (4) | Team **width** decreases and team **length** increases as the ball moves closer to either goal. | - The individual player area for a female footballer in practice sessions should not exceed 110$m^2$ |