Developing Performance in Sports Teams Through a Collective Homeostasis Model Supports Regulation, Adaptation, and Evolution in Competition

SANTOS, Ricardo <http://orcid.org/0000-0002-3208-9033>, RIBEIRO, João, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123> and GARGANTA, Júlio

Abstract: The collective homeostasis model, grounded in ecological dynamics, has recently been proposed to explain the self-regulating individual-environment interactions that are necessary to conceptualising sports teams as collective homeostatic systems. Based on these insights and given the capacity of humans to construct and adapt their ecological niches, this article explores the creation of enriching sporting contexts for the development of adaptive player-environment interactions in competitive team sports. This model of adaptation emphasises the importance of creating a sports niche rich in shared affordances to enable team coordination through the development of individual and collective homeostasis in different sub-phases of competitive performance. In a homeostatic sports system, principles of play advocated by coaches allow players to intentionally coordinate and adapt their actions to shape the collective identity of the team. The team's identity is shaped by the synergetic development of collective attractors (stable system states) emerging at specific scales of complexity. This is facilitated through the manipulation of constraints by the coaching and support staff. These ideas have important implications for implementing team sports training and performance preparation, helping to transform the self-regulating tendencies of players through adapting their behaviours to dynamic performance contexts.

Keywords: Sports Teams; Individual Homeostasis; Collective Homeostasis Model; Performance Preparation; Ecological Niche, Skill Adaptation

1 Introduction

In this paper we explore how understanding homeostatic processes in human behaviour (conceptualised as person-environment transactions) may contribute to a renewed perspective on adaptive performance in team games like football. Throughout this analysis we seek to illustrate that behaviors of individuals striving to enhance their functionality, through learning and performance development in a sports team, can be likened to a process of homeostatic adaptation. This idea has been captured as one of the main foundations in a new model of team game performance developed by Santos et al. (2023) termed *collective homeostasis*, which aligns with key principles of complexity science and dynamical systems theory. The utility of considering sports teams as homeostatic adaptive systems lies in how this modelling guides our investigation of player behaviors, in cooperating and competing, suggesting that the application of this perspective may influence the evolution of football as a cultural and social activity. Based on the fundamental principles of this contemporary model, and taking into account that homeostasis functions at all levels of biological systems, independent of scale (Torday, 2015a), we explore how these ideas may contribute to the development and performance of sports teams.

Here, we specifically examine the importance, for collective system (re)organisation, of the homeostatic process in biological systems, credited with a fundamental role in species development, including humans (Damásio, 2017). This analysis is based on the understanding that homeostasis should not be framed merely as a synchronic (real-time) servo-mechanism that maintains system status quo in organismic physiology, but rather as a dynamic process of system self-regulation in environmental transactions. As such homeostasis is an organising principle by which systems adapt their behaviours over different timescales (Torday, 2015b). The capacity of a system to adapt to a perturbation and maintain organism-environment homeostasis depends on the variety and quality of learned, functional responses it can develop and exploit.

To explore this concept, we will first discuss the connection between the functioning of sports teams and the collective homeostasis model in Section 2: *Sports Teams and the Collective Homeostasis Model*. In Section 3: *What Makes this Model so Enriching for Sport Teams' Performance?,* we outline the reasons why the collective homeostasis model significantly enhances team performance. Section 4: *Components of the Homeostatic Model* examines how this model supports the development of its key components. Finally, in Section 5: *Can a Collective Homeostasis Model help to explain the evolution of game dynamics in team sports?*, we offer insights into how this model elucidates the evolution of game dynamics in team sports.

2 Sports Teams and the Collective Homeostasis Model

Sports teams have been conceptualised as complex adaptive systems composed of different interacting components (individuals) which develop synergetic, cooperative relations, through practice and experience, to achieve successful performance outcomes (e.g., (Davids et al., 2013; Duarte et al., 2012; Passos et al., 2016). One of the biggest challenges for a sport team is the ability to maintain integrity and identity (Garganta et al., 2013), i.e., some degree of coherence in the way that they approach performance as a coordinated unit to achieve successful outcomes in a dynamic competitive environment. Players seek to use self-regulating tendencies, supporting them in satisfying the constraints of a competitive performance environment in sport, as captured in a model of *collective homeostasis* (Santos et al., 2023). In this paper, we show how this model can help inform the development and refinement of the adaptive responses of sports teams in solving problems linked to emergent context-dependent constraints of performance during training and competition e.g., the team must be prepared to attack and defend simultaneously.

Santos and colleagues (2023) defined collective homeostasis as the regulatory process within teams that enables them to effectively respond to different challenges in the sporting context. They highlighted that collective homeostasis reflects the inherently adaptable process underlying organisation and function in team sports, which emerge from the cooperative, synergistic processes developed by players during practice and preparation for competition. This model consists of four components: a) **players**, as self-regulating agents who achieve intended performance goals by coupling perception and action systems; b) this intentionality in performance importantly acts as a **set point** or set of principles of play which guide or shape a sports team`s performance approach. Intentionality acts as a ‘specific control parameter’ to shape the order that emerges in a dynamical system (Kelso, 1995), pertaining to a specific performance model for a team (which educates the intentions of athletes); c) an **identifier**, that corresponds to a set of aggregating ideas and intentions shared by players (which frame the game model); d) the self-organising system **adapter**, which continuously receives information from the players, promoting the search of a field of intended adaptive responses. As illustrated in Figure 1, these sub-systems function by detecting changes or disturbances in a regulated (informational) variable relative to boundaries of viability – that is, the team´s organizational references, which maintain balance and integrity. When a key system variable deviates from its set point and approaches its functional boundaries of viability, it prompts a search for adjustments in system behaviour to bring the regulated variable within its tolerance limits, closer towards the set point value.

The homeostatic regulatory model explains how adaptive behaviours in the collective system emerge from training to fine-tune self-regulating tendencies underpinning team performance during transactions with the competitive performance environment, regulated by key information sources (Santos et al., 2023).

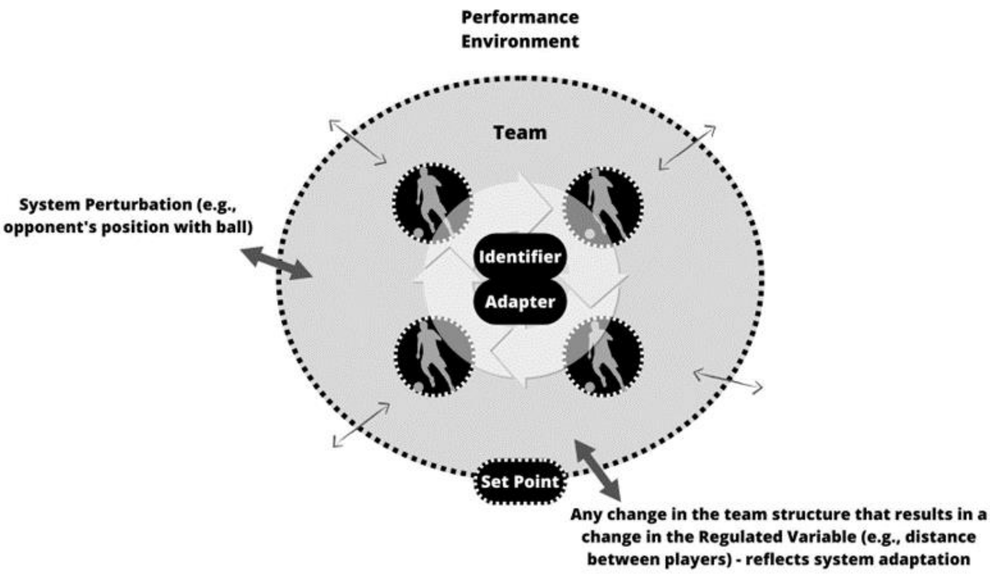

Figure 1. Homeostatic regulatory model in a sports team, adapted version from the collective homeostasis model by Santos et al. (2023)

2.1 Collective system attractors shape team performance identity

In team sports like football, performance (the ongoing coordination processes within individual players and between teammates and opponents) is a dynamical system (Davids et al., 2005). The development of a team's performance identity is based on the coherence of the collective system attractors, developed in training, i.e., collective, stable coordination tendencies towards which the behaviour of players and teams tend to converge more often under the specific constraints of competitive performance (Seifert et al., 2013). These collective system attractors (stable organisational tendencies) have a fundamental role, constantly shaping a team's coherence and identity, enabling the formation of a meaningful, shared understanding (attractor landscape) between all players in the squad. Establishing system attractors in practice supports the dynamic and self-regulatory homeostatic processes that can establish meaning and coherence for a team, helping it express its collective performance identity (e.g., tactical style, playing philosophy). In this way, collective system attractors have direct implications for the effective and efficient functioning of a team's homeostatic regulatory activities which need to be worked upon and developed in training and performance preparation. Indeed, the self-similarity nature of sports teams, considered as collective dynamical systems, implies that attractor properties may be observed to shape system tendencies at macroscopic and microscopic levels of analysis (Araújo et al., 2014).

More generally, humans have a capacity to act as niche constructors i.e., through their activities and choices they actively modify their own and each other's ecological environments, known as *niche specification* (Gibson, 1979). Gibson (1979) proposed that biological organisms inhabit and design eco-niches which contain relevant affordances (opportunities for action) available to guide their interactive behaviours with the environment. Exploiting these adaptive tendencies, the development of efficient homeostatic regulatory processes in sports teams may be predicated on sport practitioners developing an eco-niche in training and performance preparation. Indeed, Rothwell and colleagues (2021) invoked the concept of an eco-niche aligned with an ecological view of learning and development in sport organisations. They argued that successful team performers become skilled at perceiving surrounding information (e.g., events in the performance environment, the location of a scoring area to attack or defend, distances and gaps between teammates and opponents, and timing of player movements with respect to the ball) to guide their interactions with a performance environment. Thus, an initial stage in developing a homeostatic regulatory model to underpin team performance could be founded on developing an eco-niche in training to help players to express their agency on the field, by using available affordances, and ignoring others, in a performance landscape.

These key ideas have important implications for team sports players seeking to coordinate their actions together to achieve performance goals consistently during competition. Based on an understanding of the interrelated functioning of the components of this model, a set of ideas and perspectives, applicable in training, is presented to illustrate how a niche may be constructed in team development and performance preparation. This modelling approach can be implemented to effectively harness and exploit the self-regulation tendencies that emerge in sports teams, conceptualised as complex adaptive systems (Davids, 2015).

The proposed approach may provide novel insights for coaches, practitioners, and performance analysts regarding the design of training environments to enhance team organisation and functioning during competitive performance.

3 What Makes this Model so Enriching for Sport Teams' Performance?

In neurobiology, the homeostatic mechanism is a macro-system priority for maintaining the longevity, health and adaptive functionality of an organism (in sports contexts, this refers to the athlete and the team). However, this priority is dependent on the effective and efficient interactive functioning of other sub-systems operating at different scales of complexity (micro-meso-macro). Conceptualised as adaptive organisms, sports teams aim to compete successfully in their *sports battles* (winning in a competitive environment). Their regulatory processes, crucial for evolving into a successful competitive entity, depend on micro-level homeostasis aligned with the overarching principle of collective homeostasis.

3.1 Micro-homeostasis: A reality in team sports performance

A system exhibits homeostasis at many different scales of analysis in maintaining the relationship between function and performance. In dynamical movement systems, homeostatic fluctuations at different levels of the system have a role in achieving the adaptive re-organisation needed to achieve successful performance outcomes in a consistent way, exploiting inherent system degeneracy (Araújo & Davids, 2011; Santos et al., 2023). The 'interaction-driven architecture' (Bell et al., 2019) has been formally proposed as part of a theoretical explanation for how coordination and coordination variability can produce consistent performance outcomes in movement systems. These ideas are also important for understanding how homeostasis underpins dexterous movement coordination in athletes (micro homeostasis) and functional coordination between agents in a collective movement system (macro homeostasis) in striving for a team performance goal.

Micro homeostasis consists of individualised homeostasis effects that allow each player, individually, to co-adapt their behaviours with others during team performance e.g., modifying (reducing or increasing) values of key information variables that help regulate interactions with a performance environment. These informational constraints include values of interpersonal distances, approach velocities in co-adaptive movements of teammates and opponents, and available space in pressure zones. A football team in *ball possession*, framed by the key intention of attacking the opposition goal, can adopt systems of surveillance of space availability and movements of opposing players, in order to be prepared for a transitionary moment of ball loss. Consequently, micro homeostasis in this case is dependent on players' individual psychological (e.g., attentional, perceptual, decision making), technical (ball-recovery skills) and physical (e.g., speed of foot movement, agility, and power) characteristics, varying according to specific positions and player roles, predicated on self-regulation and co-interactive behaviours.

Indeed, the ability to augment performance by enriching interrelations between individual players and the team depends on an in-depth understanding of the homeostatic regulation of players and the team as a complex, adaptive system. Although important, one must not look to the aggregated sum of each player's functionality. Rather the emphasis in practice is on how players may synergise their individual homeostatic processes in co-adapting and exploiting system self-organising tendencies, when seeking to accomplish a collective task goal. The 'interaction-driven architecture' (Bell et al., 2019) of complex adaptive systems facilitates changes in individual system components (i.e., co-adapting players) to shape the way that performance outcome goals are achieved by exploiting the collective coherence of the homeostatic process in the team. Coherence and integrity of performance can emerge in a sports team through good coaching and insightful practice to support goal-directed collaborations emerging between players. These interactions can support the integration of their actions in close-knit, networked relations throughout performance that facilitates the spread of localised system fluctuations intended to influence the state of the global system (the competitive game). The constant transitions between stability and perturbation emerging from performance interactions of players can be soaked up by the global system organisation, when satisfying constraints imposed by minor local perturbations. Effects of tactical performance changes or individual contributions can develop stronger localised perturbations, leading to the emergence of new global system states of organisation (e.g., a levelling up of a game being lost) (Davids et al., 2005). This is a crucial point of the concept of collective homeostasis. The system is not destabilized by the transitions between stability and perturbation. Instead, the global organization can absorb and process these fluctuations. This is possible because the system, as a whole, is both resilient and adaptable. Collective homeostasis, therefore, is not about maintaining a static state of balance, but rather about the system`s ability to flexibly respond to disruptions arising from the interactions between its members and changes in the environment, allowing it to remain functional and coherent.

Exemplifying in football, some players may be coached to act as ‘enablers’, with their role (e.g., providing defensive balance and cover, occupying certain zones of the field when attacking) freeing up other players to express their skills in attacking areas of the field. These focused and limited performance behaviours are imbued with coordinative meaning, allowing the most creative players in the team to operate with more freedom. This freedom may allow them to exhibit exceptional technical skills and vision, passing ability, and dribbling skills to create goal-scoring opportunities in more advanced areas of the field nearer the opposition goal.

This systemic conceptualisation captures the bi-directional self-organisation processes underpinning synergy formation and the soft-assembly of different adaptive performance responses to challenges and problems faced in performance (Ribeiro et al., 2019). Training should simulate the game`s challenges, helping football teams develop the ability to use their “interaction driven architecture” to adapt and perform in real game situations. Practice designs that emphasise ‘repetition without repetition’ (i.e., performing the same task in varied ways to adapt to different conditions, emphasizing flexibility and learning rather than mechanical repetition) (Bernstein, 1967) will contribute to the team's evolution as a collective system and its continued integration and development. These types of challenging practice designs provide enriched opportunities for preparation of performance dynamics (see Otte et al., (2021), which implies shaping a sports niche for specifically developing individual and collective homeostatic regulatory systems. Next, we discuss how these homeostatic processes can be developed through the creation of an ecological niche.

3.2 Developing homeostatic processes through an ecological niche: self-similarity

When the environment or an individual athlete changes over time, there is an opportunity for behaviours that underpin their interactions to change as well. When the environment or an individual remains too stable (e.g., in a 'comfort zone' where the performance constraints are not varied enough or an individual is not challenged to adapt their actions, merely rehearsing techniques and tactical plans in practice), exploratory behaviours tend to be limited, decreasing opportunities for the emergence of novel synergies between players (Torrents et al., 2020). In essence, perturbations to the interactive performance dynamics of players in practice are needed to induce fluctuations in the athlete-environment system.

In order to enhance athlete or team functionality, coaches should seek to (re)design an ecological niche as a starting point when tasked with supporting development of specific athlete behaviours that could underpin performance excellence during competition (Rothwell et al., 2021). Insights on this practical challenge can be enhanced by understanding of self-similarity in complex, dynamical systems (Mandelbrot, 1967). Exploring self-similarity of a complex system and its components can reveal how the structure and function of a whole system (sports team) can be understood by analysing the structure and function of its parts (interacting players), providing rich insights for training and team performance preparation models (Davids et al., 2005).

In the context of football, the fragmentation of the game (Figure 2a) into smaller components while maintaining the essence of the whole (i.e., the full-sided game that is played and taught) is essential, as it preserves flows of specifying information or shared affordances (performance opportunities available in stable, collective system attractors) that regulate individual and collective homeostatic processes. Here, manipulation of task complexity and difficulty in performance scenarios during representative practice helps develop principles of play in a model scaled to specific phases of the full-sided game (Figure 2b).

These sub-phases of play need to be based on micro-components of the full game. They are exemplified in 3vs1 *[(1+GK) X (GK+1)+2]*, 2vs1 *[2 X (1+GK)]* or 3vs2 *[3 X (2+GK)]* scenarios (depicted in Figure 2b), showing self-similarity with the full-sided game. They encapsulate the complex micro-macro relationships, or principles of play, present in the full sided 11vs11 game of soccer. Guilherme (2004) argued that organizing learning tasks from this perspective, emphasizing the self-similarity inherent in such fragmentation, is a key methodological consideration in coaching, as it allows for more effective pedagogical interventions. This method of decomposing the game into its functional structures compels players to make constant decisions and solve problems, reinforcing principles of play across different game phases and periods, which collectively shape a specific game matrix (Guilherme, 2004).

From a scientific and technical perspective, it is important to distinguish between *complexity* and *difficulty* (see Garganta et al. (2013). Complexity refers to both the quality of interactions and the number of system components engaged in performance. For example, in sports teams, complexity can be reflected in the number of players available to support relational transactions (i.e., coordinated, collaborative actions during competitive performance. Garganta et al. (2013) argue that a less complex game (involving fewer players) may still be more challenging (with higher levels of task difficulty) because it places greater emphasis on the proficiency of technical actions. Consequently, players with technical deficiencies and limited game understanding may struggle to succeed.

To clarify this distinction, Figure 2b illustrates three pedagogical progressions that can be considered when developing the principles of offensive phase, specifically *penetration* (e.g., create advantageous conditions for the attack in numerical and spatial terms) and *offensive coverage* (e.g., supporting the ball carrier) during the attacking phase. For more detailed information regarding principles of play see Costa et al. (2015).

A pedagogical question that might capture readers' attention is: why start practice with a 3vs.1 (more complex due to the number of players involved) instead of a 2vs.1 activity? The problem is that, although less complex in terms of number of players involved, the 2vs.1 as a game format is highly dependent on the proficiency of technical skills from participating players. These include ball mastery skills such as good close ball control and manipulation skills, as well as enhanced dribbling and passing skills. Indeed, the two attacking players need to coordinate their tactical-technical skills under the pressure of a single defender. Furthermore, the ball carrier has only one player providing support (there is no triangular setup, which makes the play more predictable, because there are fewer affordances available) and less difficult for the defender than the 3-attacker interactions (which have more affordances available for the attacking unit). Essentially, the ball carrier needs to understand when to move the ball up field through dribbling, or to attract the defender towards them before passing the ball to their teammate and provide support. Alternatively, the 3vs.1 has a 3-player triangular setup which favors the attacking team, as there are 2 "free" players – who have more time and space, providing more affordances, while the ball carrier penetrates space around the lone defender and tries to advance with the ball up field.

Figure 2c shows the allometric control in the system (long-time “memory”) substantiated by shared affordances ‘for’ and ‘of’ other players, underlying the accomplishment of principles of play (guide players’ attention towards more effective actions and performance outcomes) in the game model emerging from individual and collective homeostatic processes. In collective homeostasis, each player is not just a passive agent but an active contributor to the regulation of the system. Individual actions directly influence the group`s overall state. In other words, individual homeostasis, aligned with the team`s allometric control, developed through both players and the team, allows for the regulation of the homeostatic process while also enhancing the team`s adaptive capacity.

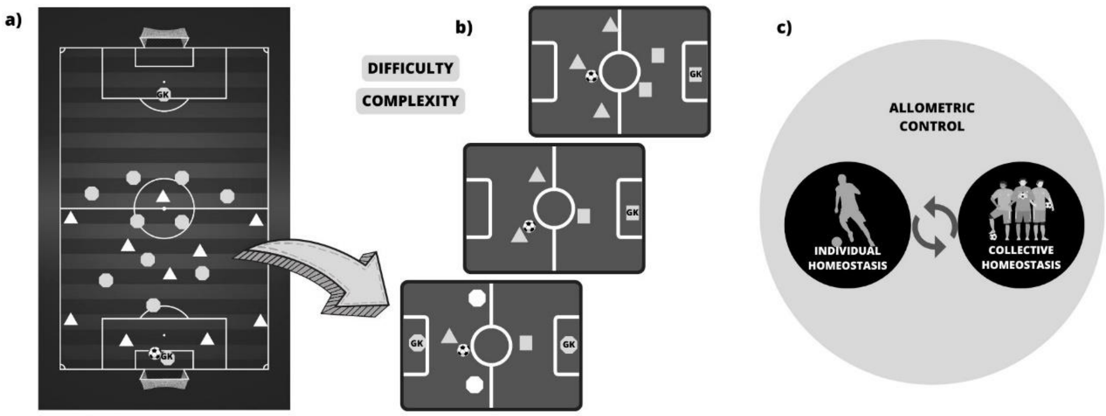

Figure ***2.*** *Illustration of a sports niche:* ***2a****: fragmentation of the game with representation of the whole;* ***2b****: managing task complexity and difficulty in specific game formats (e.g., 3vs.1 [(1+GK) X (GK+1) +2]; 2vs.1 [2 X (1+GK)]; 3vs.2 [3 X (2+GK)]) to develop principles of play;* ***2c****: regulation and adaptation of individual and collective homeostasis through allometric control.*

So, these practice design manipulations, are characterised by different affordance landscapes, and may also have implications for self-regulated learning and consequent development of individual and collective homeostasis. Therefore, three fundamental points must be considered: a) the individual (coach and each player) can promote significant changes in environmental conditions (they both act as ‘niche constructors’ (Rothwell et al., 2021); b) such modifications in practice design can tune players' intentions and attention, acting as selection pressures (i.e., help them perceive relevant information and utilise shared affordances to achieve intended performance outcomes); c) evolutionary responses (at the level of the homeostatic regulatory process – emerging at different system levels – from individual to collective) can induce such contextual changes.

In sum, combined with the perspective that collective homeostasis provides on self-regulating performance dynamics in sports teams, team sports training can provide an ideal stage for the transformative process of “*Homo Sportivus*” (Bento, 2007), supporting the production and reproduction of a collective identity. In the next section, we consider the development of each component of the homeostatic model.

4 Components of the Homeostatic Model

4.1 Players – “Unity and Collective Identity”

In the model of Santos et al. (2023), players represent a group of highly attuned, information-seeking agents within a team, continuously interacting and playing a decisive role in: (i) creating information through movements and performance actions that influence the behaviour of teammates and opponents, and (ii), shaping the dynamic values of key performance variables to help collective systems transition through states of stability, instability and metastability (i.e., a state in which a system remains stable for a period of time but is not in its most stable state) in their intrinsic dynamics (organisational tendencies) (Kelso, 2022). So, players develop the capacity to produce novel information based on the multiple ways they interact with the performance landscape in terms of perceptions, previous experiences, knowledge of the performance environment, and current competencies and abilities. Each player could engage in adaptive, goal-oriented actions/behaviours shaped by the principle of *reciprocal-compensation* (i.e., if one player contributes more or less in his/her expected role, other team elements should adjust their contributions, so that task performance goals are still attained) in the team (Araújo & Davids, 2016).

This understanding underlines the relevance for creating a performance niche in practice, conducive to the development of skill adaptation in each player, to help them attune to information and utilise affordances available in the surrounding perceptual-motor landscape. For example, when coaching a football player to improve their position in a defensive line, practice designs could provide them with shared affordances that develop attunement to information to perceive and act upon – related to the location of the ball, the goal area, and their co-positioning with immediate teammates and opponents. These sorts of training sessions must be dynamic and rich in opportunities for players to continually solve problems, make decisions and choices, perceive information to interact with the environment and coordinate their actions to (re)organise their performance behaviours.

Rather than merely rehearse a choreographed defensive formation, the implementation of a homeostatic model in practice should provide players with opportunities to exploit inherent tendencies for system degeneracy (Edelman & Gally, 2001) (i.e., achieve the same or different performance outcomes with different coordinated actions), continually (re)organising their adaptive actions, to cope with ever-changing performance constraints (Duarte et al., 2012). To achieve these collective system aims, every player needs to be supported in establishing and maintaining a homeostatic state throughout performance, which resonates with the homeostasis of the collective system. Collective system functioning is highly dependent on the unique contributions of each individual, since each player has singular characteristics (e.g., skill set, decision-making, experience levels, among others) which are adjusted and integrated to enhance whole system functioning.

A fundamental aspect of this, which must not be neglected for the proper functioning of this whole homeostatic process, concerns athlete self-regulation with the dynamics of the environment (e.g., Guignard et al. (2020)). Applied to sport, the self-regulatory perspective raises the question of how each player can take more responsibility for the quality of their interactions with a performance environment, continually working to improve it. Self-regulated learning emphasizes the active role of the performer in the process of learning, through exploring, discovering and exploiting the performance environment to find available key information sources to guide goal-oriented behavior (Carvalho & Araújo, 2022).

Thus, if a player is motivated toward a high level of learning and improvement and is encouraged during training sessions to self-regulate (i.e., recognizing that their attitudes, behaviours, and problems reflect their own choices), this ecological approach to practice design will increase the likelihood of performance improvement. So, the challenge is to match the opportunities and emphasis for self-regulation with respect to the environment provided in training, to the desire for self-direction exhibited by the players.

Player responsibility has been largely neglected in research on football, and yet it has a great influence on a range of behaviours, either individual or collective, related to training and team performance (Konter et al., 2019). This concern follows the same line of thought as the basic foundations of the homeostatic model and may be used as a unifying concept, since reliable functioning of individual homeostasis is essential for efficient and effective collective homeostasis.

In this way, this model considers training as a continuous, transformative-adaptive process, serving to fine-tune the performance of players as perception–action coupling agents functioning in a collective system. In this system, collective attractors play a prominent role in inducing stable states of organisation, preparing the system for performance uncertainties, and exploiting functional variability to facilitate adaptive responses to emerging environmental challenges (Duarte et al., 2012).

4.2 Identifier – "Homeo (Tactic) Regulation"

In the collective homeostatic model, the identifier component corresponds to the capacity of the team, as an entity, to perceive and act upon specified information received through each player and the dynamics of the performance environment. Essentially, players perceive information and utilise shared affordances that allow them to establish functional synergies coherent with accomplishing a set of tactical principles of play pertaining to a specific game model (Santos et al., 2023).

Neurobiological systems are 'open' in the sense of regulating their information-based transactions with an environment following fundamental rules (in biology "everything is regulated"; (Carroll, 2016). In this way, sports teams are constrained by a set of tactical principles, which provide a guiding regulatory matrix for the open, homeostatic mechanism. The performance behaviours of a sports team emerge from a dynamic interactive relationship between the information from the environment in which it exists (provided by the competitive performance context and the training sessions in which it participates) and the *internal* environment (framed by the players` specific intentions and interactions guided by principles and sub-principles of play). This relationship forms the ‘interaction-driven architecture’ (Bell et al., 2019) that supports continuous (co)adaptations within the environment, promoting the development of self-regulation capacity of players and teams. The regulatory laws of performance (tactical principles of play) underpinning players and teams` intended interactions form a powerful specific control parameter (Kelso, 1995) framing this adaptive process for the team as an open system.

Practice designs need to include specifying information (that which is available in performance environments) so that players can be attracted toward intended performance outcomes. These outcomes should consistently emerge across varying levels of complexity, from fundamental skills to more integrated and dynamic actions. This aspect is so important because: a) players create invariants in movement (by finding the collective system attractors we can identify the key performance features that coaches need to pay attention to); b) players and teams quickly transit between different states of functional stability in open, unpredictable, and dynamic environments. These insights align with key ideas of Bosch (2020) that "stability matters more than perfection"; c) the type and number of variables encompassing the dimensions of an environmental niche may vary from one team to another, i.e., teams differ in the properties used to assemble their collective system attractors – each team has its own idiosyncrasies; and d), less functional attractors can result in sub-optimal performance patterns, i.e., inconsistencies between a game model and its operationalization, or states of team organisation mismatched with the intrinsic dynamics (key performance tendencies, dispositions and characteristics of players in the squad) may create challenges in adapting player actions to a game model. The way a coaching team manipulates the key task constraints in practice will be a key determinant in developing adaptive performance behaviours, impacting the self-regulated functioning of the team as an open homeostatic system.

4.3 Adapter – “Collective Frequency”

The coaching team´s role (in the development of collective homeostasis) is not to rehearse specific techniques or choreograph tactical patterns that are controlled to the *nth degree* in endless repetitions during practice. Rather, is to help instill positive and sustainable adaptive habits in players that enable them to continually learn, grow, and develop (Connolly, 2017). Earlier we noted the importance of the available ‘interaction-driven architecture' of players and teams in predisposing such complex systems to explore, discover and adapt actions. These inherent system tendencies require practice activities and tasks which are designed to support the exploitation of exploratory actions through practice characterised as 'repetition without repetition' (Bernstein, 1967). During this process, experiences emerge through players' exposure to rich and varied training contexts, which can cause collective system fluctuations and perturbations, soliciting synergetic adaptations of players. Coaches need to design practice task constraints, full of representative game challenges and problems that help these adaptations emerge and become configured in line with a team's collective identity. Only when a team develops a collective identity (grounded in well-defined, collective system principles, with stable attractors, and incorporated by all players) will it be possible to change behaviours that compromise the *core personality* of the team (Lobo, 2019). Collective identity provides a shared framework and sense of purpose, aligning individual actions with the team`s overall goals. When all players understand and commit to these common principles, they are better equipped to modify behaviors that may undermine the team`s cohesion or effectiveness without losing sight of the team`s core essence. Thus, the adapter component is essential for homeostatic regulation in the *(re)organisation* of constant adaptations.

The self-organising system adapter corresponds to a collective capacity distributed between all players in the team, a tendency through which they interact with the performance environment by continually receiving information from teammates and opponents, filtered by the identity of the team, framing a set of adaptive intention-driven responses (Santos et al., 2023). Like the identifier, the adapter component depends substantially on the team's self-organising, soft-assembly tendencies and synergy forming dispositions (Santos et al., 2023). Psychologically, the squad players need to adapt to this performance philosophy over time, supported by the adapter.

The adapter initiates the appropriate team (re)organisation for exploiting an *opportunity for (inter)action* resulting from a perturbation signalled by regulated performance variable values (captured in distances, spaces, gaps, directions, co-positioning, movements of players), enhancing the capacity players in the team to perceive and act upon available opportunities for action – affordances that can be utilised in performance environments (Gibson, 1979). For example, in football, a team losing ball possession, provides an opportunity for players to immediately act on that loss, perhaps by increasing pressure on the opposition ball carrier and closing off spaces for passing lanes to teammates. These opportunities for adaptive responses must be coordinated to be exploited and efficient and effective, always commensurate with principles of play adopted in performance preparation. The key point is that there are no perfect homeostatic regulatory processes, and it is important to know how to deal with system error. Performance errors have been considered a natural part of the learning process in sport (Burton & Raedeke, 2008), and the correction of such errors in team sports is of central concern to coaches. In an ecological dynamics' rationale, the aim in learning is not to mechanistically reproduce an ideal movement technique in competitive performance, that has been rehearsed in practice. This theoretical perspective has clear implications for coaching in practice: 'errors' may be viewed as opportunities for continuous refinement and adaptation in (re)assembling system performance. Players need to be exposed to surrounding information (systemic and, less frequently, augmented) that is continuously available to adapt and (re)assemble their performance. It is important, therefore, to create learning contexts so that players develop a functional interpretation of performance feedback and learn to deal with this surrounding (and augmented) information constructively (Homsma et al., 2007). Players need to understand that the homeostatic regulatory process is likely to be put under pressure or fail at certain critical moments in competitive performance (and in training). But the challenge is not to allow individual homeostatic failures to affect the coherence and integrity of the entire team structure (collective homeostasis). Therefore, it is necessary to promote the willingness to take full ownership of one´s behaviour (expressed in the common mantra: 'no excuses'), and be open to seeking surrounding, and augmented information (from coaches and performance analysts) available in individual and collective settings within football practice (Konter et al., 2019).

To support their openness to relevant feedback information, it is also important for players to experience opportunities in practice that enhance their skills in attuning to relevant perceptual information to regulate their actions. Training is a vital tool to shape this tuning process (Teques et al., 2017), offering players the opportunity to continuously explore flexible solutions, in terms of understanding how and where to explore, so that they can exploit the collective attunement to shared affordances that support team coordination (McGuckian et al., 2017).

The search for new and better adaptive responses (e.g., constrained by specific strengths or weaknesses of the opposition on the day) takes us to the set point of this homeostatic model.

4.4 Set Point – "Measure the Functioning of the System"

In the collective homeostatic model, understanding of the set point is directly associated with tactical principles of play. These principles pertain to a game model that frames allometric control in team performance (Santos et al., 2023). Different set points (at different time scales) are available to the regulating system, providing flexibility to respond effectively to a large variety of performance demands and uncertainty. The emergent value of the set point and its adaptation is dependent on the self-regulating tendencies of a team, based on its performance identity and the system's history (Santos et al., 2023). The set point is crucial for assessing how well the system (i.e., the team) regulates itself, helping to determine whether any team variables need to be adjusted. For example, this might include changing team shape, such as switching from 1-4-4-2 to a 1-4-5-1 when defending the goal, or modifying the pressure tactics used after losing ball possession. The latter can be more passive or more aggressive depending on the specificity of demands solicited by the current state of the game, the location on field, the characteristics of the opposition or the positioning of colleagues nearby and related to any past game action in a similar scenario.

Augmented information from performance analytics will provide systemic feedback to help the coaching team and sport science staff to continue developing and building the most adaptive learning environments. Once again, this process is predicated on parameters that confer the team's collective performance identity and the principles that guide the regulation of the players' performance behaviours. This process will be (or should be) the starting point for analysing and updating the functionality of team interactions via the homeostatic regulatory process.

5 Can a Collective Homeostasis Model help to explain the evolution of game dynamics in team sports?

As mentioned by Santos et al. (2023) the 'survival' of a sports team in competition depends on the maintenance of collective homeostasis in key variables. Sport teams (and their form of organisation) will *survive,* and even thrive, as long as they can accommodate system perturbations without losing homeostasis. This view of a sports team as a first-order homeostatic adaptative system implies a view of evolution as a second-order adaptive process acting on the parameters of the first-order regulator.

A sports team is a homeostatic system with organizational parameters constrained by its tactical principles of play. Its learning contexts in training may be seen as a part of the homeostatic (re)organisation. Given that niche construction has played an important role in human evolution (Antón et al., 2014; Kendal et al., 2011), in a similar way, changing selection pressures on tendencies for team coordination behaviours to emerge and stabilise, by manipulating task and environmental constraints, could help us to understand the evolution of behavioural dynamics in collective system performance, to identify self-regulation tendencies. The adjustment of these selection pressures on self-organisation tendencies through training provides a functional 'chaos + feedback' loop that allows continuous (inter)action opportunities to be created and/or dissolved due to context-dependent changes. In this case, changes in context-dependent constraints, promoted in training and that, consequently, change the information present in a practice task, contribute to the development of self-regulating adaptive responses.

6 Summary and Conclusions

Throughout this paper we have sought to illustrate that learning and development of performance in sports teams can be likened to a process of homeostatic adaptation. The utility of considering sports teams as homeostatic adaptive systems lies in the way it can guide our exploration of their behaviours. Where we observe constancy in the face of perturbation, we should look for regulation and homeostasis. Where we see homeostasis, we should look for homeostatic adaptation. Ascribing different parts of a sports team to different roles in the homeostatic adaptive system framework, can lead to a better understanding of team behaviours. In this sense, understanding the important process of adaptation and development can lead us to understand evolution (of teams and game dynamics in team sports) as a special case of homeostatic adaptation.

Some forms of system (re)organisation will be better at withstanding perturbations than others and will, therefore, survive for longer, as with certain ways of performing. If successful, these system states may persist for a prolonged period until they are challenged by more efficient and effective changes in performance, such as constraints imposed by changes in tactical structures of other teams or even through changes in competitions e.g., through new rules, events, technology and equipment. The evolutionary adaptation of teams in sport and their performance certainly contributes a lot to the evolutionary dynamics of competitive contexts, like football, as a global phenomenon.

This perspective adds a new dimension to our over-arching theme of homeostatic adaptation providing a fundamental principle of human performance behaviours, when viewed at all dimensions of the system. The consideration of evolutionary constraints on the dynamics of sports teams, as well as the game itself, as a result of homeostatic regulation and consequent adaptation is an innovative way of thinking. Focusing on the evolving nature of sports performance highlights the importance of team preparation, training, and athlete development. These processes are grounded in the interaction between the environment and the performer, requiring continuous micro-level adaptations (such as athlete learning and development). This 'interaction-driven architecture' approach forms the foundation of macro-level homeostasis in team preparation.

The conception of collective homeostasis, rather than being a doctrine of constancy, is fundamentally a doctrine of dynamics, adaptability and change. It is through interacting with constant adaptations (chaos + feedback) that the players' behaviours/ team dynamics may be aligned with evolution in competition. The contribution of the ideas and foundations of this model for the development of sports teams may help advance and refine a sports niche, rich in shared affordances that support performance preparation, skill adaptation and improvement of individual and collective homeostasis process. Understanding how each team player perceives the competitive environment and, especially, how they coordinate and interact together, will be fundamental to improve team performance as a collective homeostatic process. Future research, based on this theoretical modelling, needs to continue to refine our understanding of the individual and collective homeostatic processes at work in players and sports teams.

Compliance with Ethical Standards

No sources of funding were used to assist in the preparation of this article.

Conflict of interest

The authors declare no conflicts of interest.

References

Antón, S., Potts, R., & Aiello, L. (2014). Evolution of Early Homo: An Integrated Biological Perspective. *Science (New York, N.Y.), 345*. https://doi.org/10.1126/science.1236828

Araújo, D., & Davids, K. (2011). What Exactly is Acquired During Skill Acquisition? *Journal of Consciousness Studies, 18*, 7-23.

Araújo, D., & Davids, K. (2016). *Team Synergies in Sport: Theory and Measures* (Vol. 7). https://doi.org/10.3389/fpsyg.2016.01449

Araújo, D., Diniz, A., Passos, P., & Davids, K. (2014). Decision making in social neurobiological systems modeled as transitions in dynamic pattern formation. *Adaptive Behavior, 22*(1), 21-30. https://doi.org/10.1177/1059712313497370

Bell, C. A., Carver, N. S., Zbaracki, J. A., & Kelty-Stephen, D. G. (2019). Non-linear Amplification of Variability Through Interaction Across Scales Supports Greater Accuracy in Manual Aiming: Evidence From a Multifractal Analysis With Comparisons to Linear Surrogates in the Fitts Task. *Frontiers in Physiology, 10*. https://doi.org/10.3389/fphys.2019.00998

Bento, J. O. (2007). Do Homo Sportivus: relações entre natureza, cultura e técnica. *Revista Brasileira de Educação Física e Esporte, 21*(4), 315-330. https://doi.org/10.1590/S1807-55092007000400006

Bernstein, N. (1967). *The Coordination and regulation of Movements*. Pergamon Press.

Bosch, F. (2020). *Anatomy of agility : movement analysis in sport*. 2010 Uitgevers.

Burton, D., & Raedeke, T. D. (2008). *Sport Psychology for Coaches*. Human Kinetics. https://books.google.pt/books?id=Zipm0ZmcX6AC

Carroll, S. B. (2016). *The Serengeti Rules: The Quest to Discover How Life Works and Why It Matters - With a new Q&A with the author*. Princeton University Press. https://doi.org/10.2307/j.ctvc77k63

Carvalho, A., & Araújo, D. (2022). Self-regulation of learning in sport practices: An ecological dynamics approach. *Asian Journal of Sport and Exercise Psychology, 2*(1), 3-7. https://doi.org/https://doi.org/10.1016/j.ajsep.2022.03.003

Connolly, F. (2017). *Game Changer: The art of sports science*. Victory Belt.

Costa, I., Guilherme, J., & Garganta, J. (2015). *Para um futebol jogado com ideias: Concepção, treinamento e avaliação do desempenho tático de jogadores e equipes*. Appris.

Damásio, A. (2017). *A estranha ordem das coisas: a vida, os sentimentos e as culturas humanas* (1ª ed.). Temas e Debates: Circulo de Leitores.

Davids, K. (2015). Athletes and sports teams as complex adaptive system: A review of implications for learning design. *RICYDE. Revista internacional de ciencias del deporte, XI*(39), 48-61. https://www.redalyc.org/articulo.oa?id=71032869005

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of Dynamical Systems Theory of Football. In J. C. Thomas Reilly, Duarte Araújo (Ed.), *Science and Football V: The Proceedings of the Fifth World Congress on Science and Football* (pp. 537-550). Routledge.

Davids, k., Hristovski, R., Araújo, D., Balague-Serre, N., Button, C., & Passos, P. (Eds.). (2013). *Complex Systems in Sport (1st ed.)*. Routledge. https://doi.org/https://doi.org/10.4324/9780203134610.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). *Sports Teams as Superorganisms* (Vol. 42). https://doi.org/10.1007/BF03262285

Edelman, G. M., & Gally, J. A. (2001). Degeneracy and complexity in biological systems. *Proceedings of the National Academy of Sciences, 98*(24), 13763-13768. https://doi.org/doi:10.1073/pnas.231499798

Garganta, J., Guilherme, J., Barreira, D., Brito, J., & Rebelo, A. (2013). Fundamentos e práticas para o ensino e treino do futebol. In F. Tavares (Ed.), *Jogos Desportivos Colectivos: Ensinar a jogar* (pp. 199-263). FADEUP.

Gibson, J. (1979). *The ecological approach to visual perception*. Houghton Miffin.

Guignard, B., Button, C., Davids, K., & Seifert, L. (2020). Education and transfer of water competencies: An ecological dynamics approach. *European Physical Education Review, 26*(4), 938-953. https://doi.org/10.1177/1356336x20902172

Guilherme, J. (2004). *Conhecimento Específico em Futebol. Contributos para a definição de uma matriz dinâmica do processo ensino-aprendizagem/treino do Jogo* FADEUP].

Homsma, G. J., Van Dyck, C., De Gilder, D., Koopman, P. L., & Elfring, T. (2007). Overcoming Errors: A Closer Look at the Attributional Mechanism. *Journal of Business and Psychology*, *21*(4), 559-583. http://www.jstor.org/stable/25092978

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. The MIT Press.

Kelso, J. A. S. (2022). On the coordination dynamics of (animate) moving bodies. *Journal of Physics: Complexity*, *3*(3), 031001. https://doi.org/10.1088/2632-072X/ac7caf

Kendal, J., Tehrani, J. J., & Odling-Smee, J. (2011). Human niche construction in interdisciplinary focus. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *366*(1566), 785-792. https://doi.org/10.1098/rstb.2010.0306

Konter, E., Beckmann, J., & Loughead, T. (2019). *Football Psychology: From Theory to Practice*. Routledge. https://books.google.pt/books?id=SVMinQAACAAJ

Lobo, L. F. (2019). *O Futebol com que Sonhei - Como eu vejo o jogo - Artes e estilos, histórias e memórias*. Contraponto.

Mandelbrot, B. (1967). How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension. *Science*, *156*(3775), 636-638. https://doi.org/doi:10.1126/science.156.3775.636

McGuckian, T., Askew, G., Greenwood, D., Chalkley, D., Cole, M., & Pepping, G.-J. (2017). The impact of constraints on visual exploratory behaviour in football. In *Studies in perception & action XIV: Nineteenth international conference on perception and action* (pp. 85-87). Taylor & Francis: Abingdon, UK.

Otte, F., Davids, K., Millar, S.-K., & Klatt, S. (2021). Understanding How Athletes Learn: Integrating Skill Training Concepts, Theory and Practice from an Ecological Perspective. *Applied Coaching Research Journal*(7), 22-32.

Passos, P., Davids, K., & Chow, J. Y. (2016). *Interpersonal coordination and performance in social systems*. Routledge.

Ribeiro, J., Davids, K., Araújo, D., Guilherme, J., Silva, P., & Garganta, J. (2019). Exploiting Bi-Directional Self-Organizing Tendencies in Team Sports: The Role of the Game Model and Tactical Principles of Play. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02213

Rothwell, M., Davids, K., Stone, J., Araújo, D., & Shuttleworth, R. (2021). *The talent development process as enhancing athlete functionality: Creating forms of life in* *an ecological niche*. Routledge. https://www.routledge.com/Talent-Identification-and-Development-in-Sport-International-Perspectives/Baker-Cobley-Schorer/p/book/9780367

Santos, R., Ribeiro, J., Davids, K., & Garganta, J. (2023). Sports teams as collective homeostatic systems: Exploiting self-organising tendencies in competition. *New Ideas in Psychology*, *71*, 101048. https://doi.org/https://doi.org/10.1016/j.newideapsych.2023.101048

Seifert, L., Button, C., & Davids, K. (2013). Key Properties of Expert Movement Systems in Sport. *Sports Medicine*, *43*(3), 167-178. https://doi.org/10.1007/s40279-012-0011-z

Teques, P., Araújo, D., Seifert, L., Del Campo, V. L., & Davids, K. (2017). The resonant system: Linking brain-body-environment in sport performance. *Proggress in Brain Research*, *234*, 33-52. https://doi.org/10.1016/bs.pbr.2017.06.001

Torday, J. S. (2015a). A central theory of biology. *Med Hypotheses*, *85*(1), 49-57. https://doi.org/10.1016/j.mehy.2015.03.019

Torday, J. S. (2015b). Homeostasis as the Mechanism of Evolution. *Biology (Basel)*, *4*(3), 573-590. https://doi.org/10.3390/biology4030573

Torrents, C., Balagué, N., Ric, Á., & Hristovski, R. (2020). The motor creativity paradox: Constraining to release degrees of freedom. *Psychology of Aesthetics, Creativity, and the Arts*. https://doi.org/10.1037/aca0000291