# An Ecological Dynamics theoretical framework for understanding performance, learning and development in football.

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## Introduction

This chapter introduces key principles, concepts and ideas in the theoretical framework of Ecological Dynamics, related to the performance context of association football (soccer). There is a special emphasis on the dynamical transactions that emerge between players, coaches and support staff with the performance contexts of this team sport. This chapter provides insights on the theoretical background for readers to make connections with subsequent chapters, highlighting their relevance for analysing performance, and for designing practice activities and programmes, in order to develop athletes throughout their career and prepare them for competition. This book focuses on how skills are learned, as expertise and knowledge of the competitive environment in football are refined through practice and experience.

To achieve these aims, the book draws upon the psychological study of human behaviour, especially in the applied scientific domain of motor learning. Historically, a range of different theoretical perspectives and conceptualisations for explaining human behaviour have emerged in psychology. This variety of theories has led to an assortment of distinct perspectives for framing key concepts commonly considered important for motor learning like *practice*, *instructions, feedback*, *repetition* and *task design*. The principles and laws of behaviour underpinning psychological theories also differ, with distinct preferred methodologies for analysing learning behaviours at different levels. The extensive range of different theoretical perspectives available to describe and explain human behaviour is a sign

of a vibrant and healthy, independent scientific sub-discipline (motor learning) in a highly popular scientific discipline (psychology). In the (not-so-distant) past, motor learning and skill acquisition were originally taught in many university courses in sports science as part of a psychology of sport performance module (for example, going back to the birth of sport science in Europe in the 1970s).

As the study of movement behaviour has grown rapidly in the past few decades, there has also been simultaneous growth in applied scientific knowledge helping to develop explanations of performance, learning and development, as well as research methodologies for analysing and understanding skill and expertise in sports like football. These advances have led to the emergence in recent years of specialised courses and hubs of excellence in motor learning, skill acquisition, coaching, coach education, performance analysis and talent development.

## Ecological Dynamics: The emergence of a distinct theoretical framework for motor learning and performance

The growth in popularity and interest in human movement has led to rapid development of theories competing for attention. This provides a perplexing challenge for sport practitioners: "Which theory should I follow for guiding principles in my professional practice?" Occasionally, we have come across practitioners who would love to simply 'pick & mix' (i.e., create a fusion of) concepts and constructs that they are curious about, from different theories, regardless of their distinct meta-theoretical (philosophical) foundations. Their aim is to create a broad scientific 'smorgasbord of principles' of scientifically-founded, practice methodologies. But that is a challenging task because of the profound meta-theoretical differences in the philosophical roots and rationales of different theories developed for explaining human behaviour. Scientific theories can differ greatly in models, metaphors and conceptualisation used for describing, explaining and applications of phenomena (for a detailed explanation of the problems of a 'pick & mix' approach in psychology, for example, see Woods et al., 2024).

Metaphorically, this would be like coaches selecting key words from different languages to communicate with an individual player. Different languages have emerged from different

historical and geographical roots and there are variations in expressions, even in the specified meanings of non-verbal forms of communication. What would players be able to make of an integrated mix of Greek, Cantonese, French, Hungarian, Portuguese and Norwegian phrasing, for instance?

In short, adopting a 'pick & mix' approach could be a recipe for confusion, misconceptions and poor understanding. Many theories have different ways of conceiving and explaining human behaviour, with their distinct philosophical foundations making it difficult to reconcile the main principles in using them to help people perform, learn and develop in sports like football. That typically leads most coaches to rely on a single language for communication. The same approach might be most useful in understanding motor learning principles for football coaching and training.

A major difference between varying theories of human movement, and how they relate to learning and performance in football, regards differences in preferred levels of focus (e.g., internal mechanisms or external relations; See Davids et al., 2007). To exemplify, over the past decades, there has been an emphasis in some theoretical explanations on internal neuro-cognitive, motor control processes and mechanisms (e.g., Bilodeau, 1966; Bilodeau & Bilodeau; Keele, 1968; Schmidt & Lee, 1988; Madav & Cowan, 2020). In contrast, a relational, ecological systems orientation has placed the spotlight on coordination, in individuals and within groups relative to the external, surrounding environment (e.g., Davids et al., 1994; Kelso, 2020; Kugler, 1988; Turvey, 1990).

*An ecological focus on coordination tendencies*

The perspective of all chapters in this book is framed by key concepts, methods and tools attending to the coordination of components of the human body or collective systems of humans working together (e.g., a family, group, sports team, community, society or with regards to events, features, properties and the actions of others in the surrounding environment; e.g., Kelso, 2020). This ecological perspective has been insightful in revealing that such systems express inherently collaborative tendencies, greater capacity for adaptation, and collective system self-organisation under constraints (for a summary of ideas see Kugler, 1988). Systems with inherent tendencies for self-organisation have a disposition

towards pattern-formation, that is: parts of the whole have a built-in tendency for coordinating their actions during movement. These pattern-forming tendencies can be exploited in individual players and in football teams by coaches designing practice activities and games to enhance the formation of synergies between players functioning in sub-groups (defensive players, attacking players and midfield organisers of play) (Petiot et al., 2023).

Ecological Dynamics has been introduced in depth in other previous books and the aim in this opening chapter of the book is to briefly touch upon some of the major ideas in relation to the specifics of learning, development and performance preparation in the context of association football. This book specifically focuses on significant advances in the theory of Ecological Dynamics to provide insights for understanding processes of motor performance, learning and development in football. The chapters of the book outline and apply some major ideas of Ecological Dynamics related to applications in performance preparation and analysis, athlete development, coaching, talent development and training methodology. It is important to acknowledge the underlying tenets of an ecological approach to movement behaviour in general.

## The origins of Ecological Dynamics: Meta-theoretical foundations

Ecological Dynamics is an integration of fundamental ideas and related meta-theoretical (theoretical and philosophical) foundations from ecological psychology, dynamical systems theory, and key principles of the complexity and evolutionary sciences (Araújo et al., 2006). Ecological psychology and dynamical systems theory advocate a systems orientation in explaining human behaviour. An important focus is on the role of information in forming and sustaining connections between components of a system. The complexity sciences examine how system components coordinate activity, with parts co-adapting and self-organising as surrounding conditions change. An evolutionary perspective addresses how such dynamical systems change and develop over short, medium and longer timescales. The same key principles guide system coordination and self-organisation at all levels of the whole system (Kelso, 1995).

Earlier, we discussed the importance of knowing (at least something about) the meta-theoretical foundations of a scientific theory. Ecological psychology (e.g., Gibson, 1979) and

dynamical systems theory (e.g., Kelso, 1995) are both founded on a *transactional* meta-theoretical perspective for understanding performance, learning and development, as observed by Woods et al. (2024). They highlighted the philosophical pedigree of psychological theories, like Ecological Dynamics, which differ from other theories by focusing on the *person-environment scale of analysis* for explaining human behaviours. A particularly informative, and all-encompassing, characterisation of the metatheoretical origins of Ecological Dynamics is available in the rich insights of Kugler and Turvey (1987), explaining why its transactionalist foundations are important for studying human behaviour:

"Ecological Science, in its broadest sense, is a multidisciplinary approach to the study of living systems, their environments and the reciprocity that has evolved between the two....Ecological Psychology....[emphasises] the study of information transactions between living systems and their environments, especially as they pertain to perceiving situations of significance to planning and executing of purposes activated in an environment" (Kugler & Turvey, 1987, p. xii).

We like that succinct description a lot. This is because there are many points of interest, subtle and yet profound, packed with meaning for football scientists and practitioners. We attend to the selective wording used by Kugler and Turvey (1987). First, they highlight the valuable contributions from multiple scientific disciplines in adopting an ecological perspective on the natural physical world. This viewpoint highlights that development and preparation for football performance need to relate to knowledge and understanding from many disciplines, as noted earlier. Next, they draw attention to the importance of ecology as a science for explaining the *relational transactions* that emerge between an organism and its environment. They frame ecological psychology as the study of human behaviour *in the same way*. In fact, they focus attention on the relational transactions which underpin informational (energy-based) exchanges between an individual and the surrounding environment which they inhabit. This means that footballers train hard to use onboard sources of energy (e.g., aerobic and anaerobic) to act in a performance environment. As they compete, they exploit information emerging from the energy banks surrounding them, available in the form of vision (the ball in flight, a gap or space on field), haptic (touch of the ball and feel of the ground in dribbling) and acoustic (a call from a teammate or the sounds of an opponent breathing down your neck).

An overarching concept in Ecological Dynamics is that human behaviours are information-regulated, emerging in the transactions between an individual and their environment, when performing, developing and learning. The choice of the word 'purposes' in the description by Kugler and Turvey (1987) is interesting and relevant. It signals the importance to us of an individual's *intentions* in framing how perception, cognition and action may be used in football to purposefully achieve performance goals at any skill level. In performance and coaching a player can use intentions to frame their perception, cognition and action at all times. In fact, these relational ideas resonate with one of the most powerful insights in ecological psychology, proposed by James Gibson (1979, p223) that: "We perceive in order to act, and we act in order to perceive".

James Gibson remains a major influence as a psychologist who studied perception and action. His research on pilots during the Second World War led him to the conclusion that a hallmark of skilled behaviour in humans is the ability to successfully adapt their actions to circumstances, using information that surrounds them. This information can be detected from interacting 'constraints' (put simply: 'sources of information') influencing individual performers, tasks and environments. Gibson (1979) re-focused psychology on the important relationship between perceiving and acting, instead of restricting psychology to the study of idealised mental constructs that cannot be directly accessed, nor experienced.

In practice, sport practitioners can tailor an activity to realise a specific learning outcome and design contexts which change the information that guides players' actions promoting adaptive behaviours as they emerge during match play. Over the years, these key ideas have highlighted a profound methodology for all football practitioners, helpful for developing players and preparing them for performance: A constraints-led approach in a nonlinear pedagogy.

Football coaches, trainers and sport scientists can apply these ideas in their work, with two dominant messages emerging from Gibson's (1979) insights:

First, players need to be continually exposed to practice designs which enable them to move to find information which supports further perception, decision making and action. This aim can be achieved by coaches introducing variability in conditions which challenge them to 'address' the performance context in different ways. Addressing the environment refers to different ways to orient their body, adapt their posture and regulate balance to achieve task goals.

Second, players need to be challenged to adapt their attacking actions and find innovative ways to perform actions which will influence the game (e.g., covering or exploiting space, seeking different ways to exploit affordances of space behind, between, and in front of opponents). This approach in practice might involve manoeuvring the ball past opponents, passing the ball through spaces which are inviting and playing one-twos to penetrate dangerous areas of the field.

*Performance in football is information-regulated*

A fundamental message of the Constraints-Led Approach as a practice methodology denotes that players need to learn how to act in order to search for information in practice and use it to ongoingly regulate their competitive performance behaviours. According to other insights of Gibson (1979), skilled behaviour, aka performance, is primarily dependent on finding information to utilise affordances (opportunities for action) available in a competitive performance environment. Over the past two decades, Ecological Dynamics research has revealed some of the important affordances which invite actions in team sports like football. For example, affordances have been identified in player numbers involved in practice tasks (e.g., 3v3 or 6v4), playing area dimensions and spaces (e.g., Silva et al., 2015; Vilar et al., 2014), gaps between players (e.g., for penetrative passing: Passos et al., 2020), field locations of actions (e.g., Laakso et al., 2017, 2019), and, especially, the goals (Duarte et al., 2012). These studies have shown how affordances invite actions from players, soliciting them in training to use opportunities that become available in a football performance landscape. These research findings have shown how important it is to help learners to become skilled at using available affordances to frame their intentions and their attention during their development and in preparing them for competition.

A prominent idea in the Ecological Dynamics of football practice is that the design of practice contexts needs to closely *represent* performance contexts encountered at appropriate levels (i.e., *individualised*: training tasks oriented to the needs of each learner) in football competitions. Task constraints may, therefore, have more or less uncertainty (information to perceive and make decisions on) included, depending on the skill level of the players. Individualised task constraints can provide all-important *context* to practice activities, which is imperative for the coupling of information and movement during practice, supporting each player in developing skill and expertise (Handford et al., 1997). This is especially valuable for footballers, regardless of their position or role on field due to the dynamic nature of the game. One of the most successful coaches in the world, Josep (Pep) Guardiola, shared his experiential knowledge of coaching, describing football as '…the most difficult game in the world because it is open, and every situation is completely different, and you have to make decisions minute-by-minute.' (https://www.theguardian.com/football/2016/oct/07/pep-guardiola-exclusive-interview-johan-cruyff-unique). It is striking how synonymously aligned the practical insights of Guardiola are with the theoretical conceptualisation of Kugler and Turvey (1987). It has been known for some time that 'open systems' in biology remain engaged in constant exchanges with the flows of energy in the surrounding environment (von Bertalanffy, 1950). It is not known whether Guardiola intended to compare football to 'open systems' in nature, but the need for varied transactional adaptations by players in dynamic football performance contexts comes across in the simplicity of his words.

Indeed, the idea that a dynamical systems orientation could be useful for analysing football performance can be traced back to the turn of the last century (e.g., Gréhaigne et al., 1997; McGarry et al., 2002). Later in the first decades of the new millennium, a significant research programme began to capture what information regulation means in football performance, seeking to understand what dynamical ideas on coordination, synergy formation and movement system (re)organisation could imply for skill learning, coaching and practice in football (e.g., Chow et al., 2006, Chow et al., 2008; Davids, Lees & Burwitz, 2000; Davids, Shuttleworth & Araújo, 2005).

A dynamical orientation highlights the importance of understanding the scaled interdependence of analysing coordination behaviours at the individual and (sub)group

levels, examining how changes at one level (individual) may influence performance at other levels (sub-groups and the team). In the past decades, data from investigatory analyses in the Ecological Dynamics literature have exemplified how football performance has been analysed at more local (individual) to more global (team) levels of performance. For example, the use of tracking systems at elite levels of competitive football have provided augmented information to inform in-depth analyses of the spatial-temporal behaviour of players, from which performance indicators become available to use (e.g., tracking the stretch index of an attacking team, logging the team centroid at different moments, using heatmaps, or surface area measures to record the pattern-forming tactical tendencies of teams). These indicators for performance analytics have provided relevant insights about the performance tendencies of players and teams, helping to identify pattern-forming tendencies in teams and in sub-groups of players that may be linked to performance at different moments in competition. Contemporary machine learning methods support the detailed search for team performance patterns that may not be identifiable using less fine-grained levels of analysis (e.g., only recording use of space). The guidance of concepts and methodologies from Ecological Dynamics can add value to the use of artificial intelligence to identify performance zones of high interest during competitive football which captures the dynamic convergence of players into specific areas of the field, when defending, attacking or transitioning (Araújo et al., 2021).

In football, individual players need to coordinate their actions together, seeking to function as part of a coherent unit during competitive performance, forming a collective synergy (small sub-group of cooperating players coming together to achieve an intended performance goal). In a goal-oriented synergy (spontaneously formed by a sub-group of players to achieve an intended task goal: defend, attack, transition, maintain possession), the degrees of freedom of each individual in the whole collective system (team) become coupled, enabling the degrees of freedom of different individuals to adapt and adjust to each other's movements. The chapter by Carrilho et al. in this book highlights relevant concepts, principles and tools of Ecological Dynamics which enable an understanding of coherent and dynamic team actions. Particular attention is paid to the environmental and task constraints of performance contexts that inform the emergence and decomposition of *soft-assembled* (loosely-formed) team synergies (see also Carrilho et al., 2020). In practice, this process of soft-assembled synergy formation (spontaneous self-organisation of cooperative relations between players) can be enhanced through their attunement to information for shared affordances (Silva et al,

2016). As mentioned earlier, the use of tracking systems in football has supported a deeper analysis of the spatial-temporal behaviours of players, from which team performance indicators have emerged for use. In Ecological Dynamics, the guidance provided for these indicators has created new insights about the coordination tendencies of players and teams, helping analysts to find patterns that could be linked with successful performance. The guidance provided for the use of artificial intelligence can help to identify density zones during a football match which captures the dynamic convergence of players into specific pitch zones, during attacking events.

To summarise so far, an ecological metatheoretical orientation provides a *relational* viewpoint for explaining human transactions with their surroundings (using and creating information in the performance environment). This understanding is most useful for analysing and interpreting the reciprocity that emerges between a performer and their performance environment in sport with experience and learning (e.g., Handford et al., 1997). For football coaches and support staff, these ecological ideas suggest the value of designing practice programmes, settings and tasks, based on the constant, information-based transactions (exchanges) that emerge between competing and cooperating players in the competitive football environment. The information used to organise practice could come from: (i) key insights of motor learning theories; (ii) the direct experiences of players, coaches, trainers, and support staff in football; as well as (iii), augmented sources of data in performance analyses (Figure 1). Ideas, like these, from the theory of Ecological Dynamics have been instrumental in driving important changes in the way that applied scientists study athlete development and performance preparation in sports like football (e.g., Davids et al., 2000; Davids et al., 2005; Davids & Araújo, 2022).

<Insert Figure 1 here>

Figure 1: Sources of information to organise practice

In the next section of this chapter, we highlight some relevant principles of Ecological Dynamics for understanding football practice and performance, outlining implications for player development and performance preparation in football.

*How to practice in football?*

It is beyond doubt that practice is relevant and important for all learners seeking to develop as players and prepare for competition. Whilst a high volume of practice is important, at more advanced levels of performance, the days of merely recording the number of hours experienced in 'deliberate practice' by a learner have been superseded with a much greater emphasis on *what* is done in practice (Davids, 2000). While it remains clear that elite levels of performance in all sports, including football, substantial amounts of practice are needed, it is without doubt that *quality of practice* (i.e., focusing on contextualising and individualising programmes, activities and tasks) provides a more effective and efficient way to develop athletes and prepare them for competition. This key idea implies that children and women should not be treated as 'mini-adults' (Davids et al., 2023) or 'honorary males' (e.g., Santos et al., 2024) and their specific needs and characteristics need to be carefully considered by sports practitioners. The same idea is important for all athletes with diverse abilities and conditions in sports.

Traditionally, practice in sports like football is focused on repetition of movement techniques so that they can become automatised and 'consistent' through rote learning, whilst tactical patterns of play are rehearsed in shadow play or in unopposed settings (perhaps 11v3). This emphasis in practice is consistent with the idea that such practices are designed to support technique acquisition and compliance, consolidating memories laid down internally within the player to retain pre-determined team 'plays' recorded in a playbook manual. Indeed, many football organisations have a visual register or technical manual on how to perform specific techniques (e.g., O'Sullivan et al., 2023). This 'copy and paste' approach to practice and training is founded on historic ideas of *rote learning* which will only take a player a little way on their learning journey in football. In fact, the Russian multidisciplinary scientist, Nikolai Bernstein, writing in the 1930s and translated into English in 1967, called rote learning a 'discredited' pedagogical approach to practice. So, how does Ecological Dynamics advocate and define practice in sports like football?

*The essentials of sports practice from an Ecological Dynamics perspective*

Many of the chapters in this book discuss ideas that support a different view of practice, beyond technique repetition for 'automaticity', and rehearsal. Again, we can turn to Bernstein (1967) for inspiration. His insights pulled the area of human movement sciences away from an explicit, singular focus on motor control and development, towards the study of coordination and its acquisition. At the same time, the behavioural neuroscientist, Scott Kelso (e.g., 1995; 2024) focused our attention on the coordination dynamics operating at different levels within and between individuals, in societies, communities, teams and sub-groups. These giants of movement science provided us with invaluable insights regarding how best to conceptualise the practice of multi-articular coordination patterns in sport. For example, Bernstein provided some guidance by suggesting that: "The process of practice toward the achievement of new motor habits essentially consists in the gradual success of a search for optimal motor solutions to the appropriate problems" (Bernstein, 1967, p. 362).

Whilst repetition in practice is without doubt important for learning, in Ecological Dynamics the process of practice has been defined as a continuous search for functional coordination solutions, stabilising couplings of information and movement, which can be adapted to solve the performance problems and challenges facing an athlete or team (Chow et al., 2008; Davids et al., 2001). In this chapter, it is important for sport scientists to acknowledge this redirection of attention by Bernstein and Kelso. Additionally, research in Ecological Dynamics in the past decades has been deeply influenced by evidence for the re-conceptualisation of practice in sport, emerging in the motor learning literature (e.g., Newell, 1992; see also Pacheco et al., 2019). These contributions have revealed that the search activities of a learner should be ongoing and continuous, and important to undertake over the medium to long term. Learning can continue throughout the lifespan of an individual and according to Bernstein, learning in practice is a gradual process of seeking what he termed 'optimal' movement solutions. These insights imply the following warning: Beware of (mainly online opinion) articles proclaiming the existence of 'cheat codes' and 'hacks' to bypass the lengthy learning process!

*A brief pause…..*

This is where we feel the need to pause and explain an Ecological Dynamics perspective, differentiating between the terms *optimisation* and *optimality*. At first glance, the term *optimal* used in Bernstein's (1967) conceptualisation of practice may not seem consonant with the preferred idea of finding *functional* performance solutions, that emerge from the interaction of each individual with the practice environment. It may be confused with the idea of learning as technique *optimisation* (especially as referred to in the biomechanics literature; see arguments of Glazier & Davids, 2009). Optimisation infers that there is a unique movement execution of a technique that each learner is seeking to attain and comply with in football practice.

This approach to motor learning differs from Ecological Dynamics, where learning is considered a process of enhancing one's functionality in a particular performance environment. Enhanced performance functionality can be achieved by searching for, discovering and exploiting performance solutions which are relevant for each player in satisfying the specific task constraints emerging at any moment. In the dynamic performance contexts of competitive football, task constraints are always interacting with personal and environmental conditions which leads to subtle and important differences in adaptations of an action, as constraints change (e.g., as players age, or have to adapt to chronic physical changes as a result of conditions and injuries) and as a result of events like rule changes, equipment re-design, as well as strategical and tactical innovations. Newell's (1986) arguments suggest that the term 'self-organising optimality' may best capture the search to satisfy changing task, personal and environmental constraints over medium to long timescales. As Newell (1986) noted "…optimality principles reflect the search for a stable pattern of coordination and control that accommodates the prevailing constraints" (p348). Clearly, a major constraint on self-organising optimality is efficiency of movement (Sparrow, 2000), which, along with effectiveness, is especially important over the timescale of competitive sports performance. Hence, seeking optimality of performance solutions during skills practice is not the same as repetition for optimising (refining execution of) a movement technique. The continuous nature of this search process implies that there is a certain level of *optimality* that players could continue to seek in finding varied, adaptable, therefore functional, coordination solutions over their career. This is a subtle distinction between

terminology which we will revisit next, when discussing the principles of skill adaptation and manipulating task constraints in practice.

Therefore, practice activities in football need to be systematic, facilitating a learner's continuous transactions with the practice environment (task, related activities and a performance context), helping them come up with performance solutions which resolve the problems and challenges that they face. The search activities in football practice should be designed and developed to enhance a player's *cognising* (e.g., thinking, decision making, attending, remaining aware, problem solving), *perceiving* information (e.g., scanning for visual information, enhancing touch of the ball and feel of a playing surface) and related-football *acting* (for outfield players: controlling the ball with either foot, shooting with either foot, dribbling; for goalkeepers: catching high crosses, interceptions in 1v1s and playing the ball out with either foot).

What these insights on practice reveal is that coaches could consider re-imagining their main role, away from traditional methods of instructing, drilling, telling, informing, directing and prescribing solutions. These common activities observed in football coaching could be reduced, moderated, delayed, or better still, omitted, providing space and room for learners themselves to engage with the available information in a performance context.

In fact, giving time and space for learners to interpret and use information from their own movements (intrinsic feedback) and from augmented information (extrinsic feedback) from coaches, teachers, parents and trainers is a key principle of feedback in motor learning (Schmidt & Lee, 1988).

An ecological framing of coaching and teaching signifies that practitioners may view themselves as a 'change agent channelling the dynamics that arise from the interaction of the learner with the environment in the realisation of a given task goal' (Newell & Rovegno, 1990, p186). In later years, this role was crystallised into that of a learning designer in a nonlinear pedagogical methodology (Chow et al., 2011; Travassos et al., 2012).

*Manipulating task constraints; A key focus of football practice*

The main role of a coach and teacher as a designer of learning activities is to manipulate task constraints, taking into account the constraints on each individual learner (e.g., maturation and developmental status, experience, needs, current capacities, sex differences and more). Terminology is always important in science. The Constraints-led Approach to coaching is of fundamental importance in application of Ecological Dynamics in sports training and practice. That is why it is vital for coaches to understand the scientific meaning of the word 'constraint' as used in Ecological Dynamics, emphasising the surrounding information that continually shapes the activity of a movement system. A key focus in learning design is to identify the specific needs of each learner (understanding the physical, psychological, social demands that they are required to satisfy in football, for example). As mentioned earlier, children and adults, males and females, and those with (neuro)diverse abilities require a detailed analysis of their fundamental requirements in learning. Perhaps the essential way to meet the needs of each learner is to design task constraints which contextualise and individualise learning experiences for them. Finally, all football clubs operate under social, cultural and historical constraints of the environment (e.g., see Uehara et al., 2019). These constraints continually shape the way that perception and action are coupled by each learner in practice. Perception and action can be coupled to find and use affordances (opportunities or invitations) for action during football practice and performance.

*Learning in football: Finding ways to use affordances available in a performance landscape*

At this point we can draw links between practice as an activity of *search-discover-exploit* and the concept of affordances in ecological psychology. According to Gibson (1979) it needs to be understood that affordances are not *causes* of a movement. Affordances are possibilities or opportunities for action according to the founder of ecological psychology. What that idea implies is that the environment provides a 'manifold of action possibilities' (Withagen et al., 2012, p251), waiting to be exploited by skilled individuals. Considering these ideas, the suggestion is that practice activities could be designed to help footballers learn how to take advantage of the specific affordances available in a football landscape (context). Does this idea signify that coaches should make affordances really obvious for learners in practice? Not necessarily.

According to Withagen and colleagues (2012), practice designs could be designed to be *generative* in supporting the improved functionality of the athlete-environment relationship in sport. This is because many objects, events and locations in life can have multiple affordances, requiring an individual to learn to select and use the most relevant and functional affordances. Using the example of architecture, this idea implies that designers can produce objects or surrounds which are useful for limited purposes. It's the same in sport. This happens when coaches design practice tasks which have limited (narrow) possibilities and outcomes, e.g., requiring little decision making, problem solving and a lot of technique repetition. In contrast, there are often situations in competitive football performance when a context arises for a player which makes available different possibilities for action: e.g., dribble, shoot or pass to create a scoring opportunity or, in defence, stay close and shadow an opponent or drive into a tackle to win the ball. The highest level of opposition provides nuance and variation in events on field: there may be a high level of uncertainty in information available and decisions may not be as clear cut, accordingly.

By designing more neutral (open, generative) tasks, with many possible outcomes for players, coaches can facilitate opportunities for players to show greater adaptation, creativity and innovation in their actions. Designing tasks with *neutral* affordance landscapes can provide opportunities for players to search, discover and explore affordances which are more diverse in function. Designing practice tasks which are more *neutral* in terms of specific outcomes could better simulate the constraints of the competitive performance environment, encouraging footballers to problem solve, make decisions and seek and use different affordances in finding performance solutions. Neutral places and tasks in coaching and teaching can be conceptualised as having many affordances, which appear and disappear depending on the ebb and flow of dynamics of a performance environment. Practice designs could include, not just opportunities for action but rather specific *invitations*, soliciting players to function in a particular field of promoted actions (e.g., in a certain phase of play in football) which may be preferred by the player and coach during practice activity. Importantly, the term 'neutral' is meant to describe tasks designed without previously defined solutions, it does not imply that such tasks are not meaningful, or representative.

Specific aspects of a practice environment could be designed to include *'inviting potential'* (Withagen et al., 2012, p254), predisposing a footballer to seek and explore certain performance tendencies by creating practice designs which solicit certain actions and performance outcomes. This approach to practice design has the capacity to invite individual athletes or teams to perform in a *relational* way, learning to accept or resist the inviting potential of some affordances in the performance landscape. Herein lies the basis of self-regulation in football, emphasising how concepts such as autonomy, self-regulation and agency can be explained using a performer-environment scale of analysis (Carvalho & Araújo, 2023). According to Reed (1996, p19) self-regulation is predicated on the idea that 'organisms make their way in the world'. Here, we advocate that this is a useful way to consider how footballers could be coached to negotiate the trials and tribulations of a competitive performance environment, leaning on the coach for (more or less) mentorship, advice and guidance only when required.

In enhancing a player's self-regulation in performance, affordance utilisation can be best improved by better aligning the action capabilities of performers with the information and the affordances that become available in competitive contexts. This can be achieved by designing programmes that seek to make the person-environment relationship more *functional*. Enhanced functionality can emerge through enrichment activities: i.e., both specific (football-specific) and general (football-related) types of activities. Withagen and colleagues (2012) also suggest that environments can be designed to be more soliciting of affordances which are closely related to the effectivities of an individual performer.

A coaching team's role is to guide the athlete's attention to the available affordances in a performance environment, helping them to search for, discover and exploit them to enhance performance functionality. According to Michaels and Jacobs (2001) one can also guide the athlete's intentions in negotiating a performance environment, with regards to task goals which may help decision making and problem solving under pressure.

*How could football coaches use augmented information in practice?*

There is little doubt that the provision of augmented information to players (e.g., including verbal guidance, feedback, praise, and criticism; visual modelling of actions in video clips;

data analytics information) have been considered an essential platform for motor learning, skill acquisition and tactical training in sports for decades (e.g., Bilodeau, 1966; Bilodeau & Bilodeau, 1969; Button et al., 2020; Keele, 1968; Otte et al., 2020). Historically, feedback has been recognised as an important part of skill acquisition, education and pedagogy for almost a century and has been intensively studied in psychology with respect to performance, learning and development. A large body of research unpacked nuances and clarified understanding of feedback in the past 60 years when research on motor learning and control dominated research programmes (for a historical glimpse of those programmes, see Schmidt & Lee, 1988).

A vital supply of external feedback is from *augmented information* from coach, trainer and teacher in the form of verbal instructions provided or a visual model to observe. The term augmented informs us that this is additional information that augments the intrinsic and extrinsic feedback that an athlete may be able to perceive and use in performance and learning, Augmented information is a common, well-used source that is used in traditional pedagogies in the form of instructions and feedback during performance and learning. Previous research on the use of augmented information in practice has revealed that, to successfully support learning, there is some useful guidance available in research. For example, augmented feedback: (i) does not need to be given after every practice trial, (ii) can be used to summarise learning (e.g., provided after every 5 or 10 trials or more), and most importantly, (iii) should be delayed (i.e. not provided immediately after a player has performed a practice task (e.g., Schmidt & Lee, 1988). Research has shown that coaches need to delay providing augmented information as feedback to players immediately after the completion of an action. This is because players need some time to perceive and think about the intrinsic feedback they have experienced during recent movement. Small delays after practice trials allows time for players to reflect, think and learn from their own actions, not just relying on augmented feedback from coaches, teachers and other players.

*What are the main differences between skill acquisition and skill adaptation, and what do those differences mean for football coaches?*

Ecological Dynamics makes a fundamental distinction between *skill acquisition* (the act of memorising a technique by repeating it) and *skill adaptation* (the ability to adjust that

technique to environmental constraints). The thinking behind this distinction is that technical ability (i.e., the capacity to execute movement skills) is of little use unless you can apply it in competitive performance contexts, and good opponents make it their business to stop you doing that. One of the hallmarks of a skilled athlete in any sport is the ability to adapt their coordination patterns to solve the problems that opponents create for them. Skill adaptation can help them do that when it matters: under competitive pressure.

The transactional relationism metatheory that underpins Ecological Dynamics emphasises the importance of players developing a strong relationship with the performance environment and continuously working on it during their football career, due to changes to their bodies over their career (e.g., physical, perceptual and psychological), and innovations in playing styles, tactics and strategies. Therefore, it comes as no surprise that the study of skill adaptation is preferred over skill acquisition in Ecological Dynamics (See Chapter 6 of this book; Otte & Davids, 2023). Players need to be empowered to practise throughout their careers to continue to modify and adapt their movements, as a result of important physical, psych-emotional and socio-cultural changes, which operate at medium to longer term timescales. This is where a powerful role for movement variability has been advocated in Ecological Dynamics accounts of skill adaptation (Button et al., 2020; Chow et al., 2021).

*How is movement variability useful for players? And when is that variability not helpful in football?*
In Chapter 6, Otte and colleagues advocate that movement variability is an important aspect of skill adaptation needed to modify the way that athletes 'address' the performance environment (i.e., changing body orientation in space and re-organising motor system degrees of freedom) to achieve their specific intentions in performance and satisfy changing task constraints. Seifert and Davids (2011) highlighted two characteristics of expert levels of performance in sport, which are also applicable to football as a competitive context. First, aligned with an Ecological Dynamics perspective, Beek et al. (2003) suggested that as performers enhance their expertise and become more skillful, they develop stronger coupled relations with a performance environment. This idea implies that the nature of perception-action coupling is not the same for less skilled and highly skilled footballers. As a player becomes more skillful, they become more capable of exploiting information for performance from task constraints in order to adapt their performance behaviours. In football, enhancing

expertise to reach an elite level of performance is founded on the capability to successfully engage and interact with various related constraints in the competitive environment, exploiting them for maximum gain. An important characteristic of elite level footballers is the ability to adapt their actions to satisfy dynamic, interacting constraints. This capacity in players can be developed through the use of the *constraints-led approach* by coaches in practice. Research in Ecological Dynamics over the past decades has consistently revealed that during performance in sport, there is no ideal movement technique towards which all learners should aspire in learning and development, since coordination and control emerge from the interaction of personal, task and environmental constraints (Newell, 1986).

From this perspective, constraints shape the way that footballers exploit movement system variability to adapt their actions in the performance environment. Variability in practice contexts is so important because it is functional for skill adaptation. Therefore, elite performance in football is based on the need to interact and adapt to the competitive environment in real-time. A second characteristic for the acquisition of expertise in non-linear movement systems is to develop *adaptability*. In fact, it is not only the movement or the coordination pattern itself that is complex to achieve by the beginner, but also the level of adaptation to a performance context, i.e., a movement or a coordination pattern that responds to the interacting constraints (task environmental, or organismic) that change over time.

This idea of skill adaptation can be traced back to insights of Bernstein (1967) when he conceptualised performance resourcefulness (i.e., exploiting stability and ingenuity at the right time) as *dexterity*, defined as the *"...ability to find a motor solution for any external situation, that is, to adequately solve any emerging motor problem* ***correctly*** (i.e., adequately and accurately), ***quickly*** (with respect to both decision making and achieving a correct result), ***rationally*** (i.e., expediently and economically), and ***resourcefully*** (i.e., quick-wittedly and initiatively)" (Bernstein, 1967, p228).

Football practice designs can be programmed to help individuals develop performance dexterity (Bernstein, 1967) by enhancing players' capacity to continuously resolve performance challenges and problems with their (re)organised actions. Otte and colleagues

in Chapter 6 show how contextualisation of practice task constraints could benefit from using *repetition without repetition* in practice designs to enhance dexterity (Bernstein, 1967).

An Ecological Dynamics' view of functional variability is aligned with researchers in motor development (how movement capacities develop as children, youth and later adults grow and mature over their life course (timescale of decades) (Thelen & Smith, 1993). The dynamic systems approach to motor development showed that variation of movements was a natural part of child development (indeed throughout the life course). Traditionally, medical science with respect to child development was somewhat biased towards suspecting that an individual who showed variability in movement of having conditions impeding their progression. Historically, variability in movement tended to be viewed as a problem.

Thelen and Smith (1993) also showed that in critical periods during infancy, childhood and adolescence that a learner's development was nonlinear, caused by periods of instability, stability and even regressions in movement capacities. They argued that nonlinearity is caused by natural variations and is normal in most cases. This idea could be harnessed by football coaches who need to be aware of when children are in a period of stability in growth (slow and stable growth, with few changes to the movement system) and when children are in periods of great instability (for example, rapid growth in adolescence leading to fatigue, joint pains, disruption to sleep patterns, appearance of clumsiness due to changes in limb lengths and lack of strength). In periods of stability, learners might show higher levels of energy and willingness to practice more. These are periods which a coach might demand a little more from the learner and challenge them with more variability in practice. In periods of instability (learners showing more signs of the symptoms mentioned above) then coaches could temporarily focus on consolidating skills a little more and not challenge learners as much). Indeed, Wormhoudt et al. (2018) advocating the Athletic Skills Model (see Chapter by Savelsbergh et al.), went as far as arguing that after a child reaches Peak Height Velocity in growth, then they could be facilitated to 're-learn' a lot of the movement skills which may have been disrupted by changes to the child's motor system in the spurts of adolescence. The challenge for coaches is that children develop, grow and mature at different rates and along different timescales. So, that's why it is important to take an individualised approach to skill

learning and training, encouraging learners to explore movement variability in developing football skills.

Finally, it is important to note that not all variability can be defined as useful. This point signifies that coaches need to understand the important relationship between *variability of movement coordination* (an important foundation for skill adaptation) and *consistency of performance outcomes* (Davids et al., 2006). In football, players need to develop consistency and reliability in achieving performance outcomes, such as passing through the defensive lines successfully, dribbling past defenders without losing possession, shooting at goal accurately and goalkeepers intercepting crosses without dropping the ball. Players can achieve reliability in performance outcomes by exploiting variability in their movement to maintain consistency across different performance contexts. Thus, there is an entangled relationship between functional movement variability and consistent performance outcomes which needs to be picked apart in analysing football performance.

*Practical application of Ecological Dynamics in football*

The key theoretical ideas of Ecological Dynamic imply that football coaches can apply the principles of Ecological Dynamics on the training ground and find out how to analyse performance and design representative practice activities. The chapters in this book exemplify how key principles of Ecological Dynamics can be incorporated into training for goalkeepers and outfield players, emphasising the point that training should help players come up with multiple ways of achieving any specific performance objective which is solicited by the opposition performance (individually or in tactical patterns). Ecological Dynamics ideas are closely aligned to the fluid "relational" philosophy of playing (based on synergy formation between players in relation to the competitive environment).

*Nonlinear Pedagogy as an approach to implementing key concepts and principles of Ecological Dynamics in football practice.*

A key point to emerge from this chapter is that the game of football is complex and dynamic where moment-to-moment changes in individual and team performance behaviours are inherent. Chow et al (2011) discussed how nonlinearity in perception, action and cognition can be observed in neurobiological systems in the form of: (i) change being sometimes

disproportionate, (ii) understanding multiple pathways may be used to achieve the same performance outcome, (iii) that is a deeply engrained propensity to respond to changes in interacting constraints, and (iv), there is a functional role for movement variability that can facilitate adaptations in overall system behaviours. Since players need to demonstrate complex performance behaviours that are nonlinear in nature, it is logical to consider how pedagogical approaches could sustain such nonlinearity in performance behaviours during skill adaptation. The Constraints-led Approach, underpinned by Ecological Dynamics, is a useful model to initiate our understanding of how coordination of action emerges from interacting task, performer and environmental constraints. Nonlinear Pedagogy builds upon the Constraints-led Approach to indicate a broader framework of design principles to promote exploratory behaviours for learners (footballers in the context of this book) to adapt individualised movement solutions to solve movement challenges (Chow, 2013; Chow et al., 2021). The design principles of Nonlinear Pedagogy (NLP) are as follows (using CRAFT as a useful acronym here): 1) **C**onstraints manipulation, 2) **R**epresentativeness in practice, 3) **A**ttentional focus informational constraints that emphasizes outcome, 4) **F**unctional variability in practice and 5) **T**ask simplification to strengthen perception-action coupling. Below, we briefly explain these design principles in greater detail.

Effective manipulation of constraints is key, as described earlier. Mastering this method in coaching can help shape the emergence of functional (relevant, appropriate) performance behaviours, which can be purposefully incorporated depending on the objective of the football practice activity and the profile of the players that the coach is working with. For example, playing a 5v5 game (inclusive of a goalkeeper in each team) in a playing area the size of basketball court with full size goals can naturally offer more opportunities for shots to be taken (and defensive actions to block shots), when the coach is focusing on creating and preventing opportunities for shots on target. Task difficulty could be altered by manipulating goal target size, the number of players involved in the game and the space available. Level of intensity of the activity could be manipulated by using short periods of play with another ball fed into play as soon as one ball leaves the field. Indeed, there are numerous ways task constraints could be adapted by coaches to make the game easier or more challenging for players.

Creating representative learning designs by careful manipulation of task constraints can similarly provide numerous opportunities for action that can authentically challenge the players in game-like situations. Rather than using unopposed or passive contexts, incorporating more or less active defenders to create pressure could challenge a team to keep possession of the ball. Creating a need to advance vertically up the field in the playing area would undoubtedly also be representative of the performance environment (thus providing information rich contexts). This activity would challenge the team in possession of the ball to work out how passing lanes and movement into space could be explored, while opponents to maintain a defensive block and pressure the team in possession as opportunities arise.

Attentional focus of informational constraints that emphasises a performance outcome helps to create the tactical context for players to become less conscious of internal elements of movement control, learning to exploit self-organisation tendencies for optimal individualised movement behaviours to emerge. This NLP design principle is coherent with an emphasis in Ecological Dynamics perspective on exploiting self-organising optimality, such that the control of movement decreases as a focus of attention. For example, a shift of informational constraints away from how the planting foot should be positioned when kicking a ball, to one that focuses externally on the shape of the ball flight trajectory would allow the self-organisation of movement to surface more readily, facilitating the development of skill adaptation.

The role of functional variability has been espoused extensively in the Ecological Dynamics literature and again in this chapter. The inclusion of varied locations and numbers of opponents, variety in playing area dimensions and momentary rules of a game, in representative learning designs, would create the variability in an affordance landscape that can challenge players by providing them with possibilities for exploration and adaptation of actions.

Task simplification to strengthen perception-action couplings is also an important tool for football coaches. Simplifying a task, rather than breaking it up into isolated components, can facilitate complex movements to be reorganised and adapted. This method is also aligned

with the idea of *simplexity,* where task constraints can be incorporated to simplify the adaptation of the movement without sacrificing the complexity needed in generating the movement (see Berthoz, 2019). Task simplification can be achieved in the form of reducing task difficulty through the provision of larger spaces for dribbling and passing in small-sided football games, involving fewer opponents and increasing goal target sizes could create more opportunities for action (affordances) for the players to practice specific actions in these games. With task simplification and thus working through the idea of simplexity, multiple solutions could be made available to the player. Players could also learn to exploit system degeneracy (e.g., Seifert et al., 2016; same performance outcomes achieved in multiple different ways) would also be afforded to the players. Different ways of penetrating a defensive formation with a pass over of between defenders, using a one-two, or a dribbling action all examples of degeneracy could be exploited in football actions.

The various design principles work through the pedagogical channels of practice, instructions and feedback. These channels are the enablers which football coaches would use in their practices as they engage and develop players. The design principles in NLP work in tandem with each other and it is not realistic to decouple them or even attempt to utilise all principles in every practice session. The design principles provide the practitioner with a framework on how practices can be organised so that exploration and adaptation can be encouraged within an Ecological Dynamics approach.

Some of the chapters in this book will further elucidate the key principles of Nonlinear Pedagogy that provide an approach aligned with an Ecological Dynamics perspective to understanding and explaining human movement coordination and control.

*Synergy Formation in team performance*

Team performance in football is understood as a complex adaptive system. Players coordinate with each other forming team synergies, which form and dissipate as the landscape of affordances changes, during competition. These synergies have recognisable properties when analysing sport tasks (Araújo & Davids, 2016). One such property is *dimensional compression* which describes the reduction of the degrees of freedom (or dimensions) of the system guided by a collective variable. Another property is *reciprocal*

*compensation* which indicates the process of teammates adjusting to each other's movements. A third property is *interpersonal linkages* or *division of labour*, which describes how each player contributes to the team effort. A fourth property, *degeneracy*, focuses on the adaptable behaviour of the team to variations in the performance environment. Degeneracy is a fundamental property to study team behaviour because it can describe how teams continually adapt to the performance environment. According to Whitacre and Bender (2010), degeneracy is correlated positively with complexity, which means that the more structures (players) within the system that can execute the same functions, the more complexity exists within that system. Consequently, complexity improves holistic robustness as it allows the system to adapt to changing environmental conditions, by developing a wider range of performance solutions. In football, teams express their evolvability by developing different ways of achieving their intended outcomes and aims.

The ability to develop different ways to achieve task goals as a team, is predicated on the ability of players to perceive and realise shared affordances.  To note: the exact same principles are applied to team behaviour, demonstrating the coherence of the theory in explaining both individual and group behaviour. As players become attuned to each other, they can better detect relational information to act upon. In other words, perceiving a wider range of action possibilities increases the variability of solutions of the entire team. As it happens with athletes, teams not only adapt to environmental circumstances but also actively change the environment to create affordances. For example, a team may move the ball laterally to one side of the pitch and suddenly switch play to the other side, to take advantage of the space purposefully left open (Araújo, Brito & Carrilho, 2023).

For performance analysis, measuring team coordinated actions should consider their dynamic properties by capturing the lawful dynamical processes of self-organisation over time (Araújo, Brito & Carrilho, 2023). For example, Carrilho and colleagues measured team synchronization (dimensional compression), based on the change in every player-ball-goal angle in each of the two teams (Carrilho et al., 2020). They analysed synchrony variations to understand how teams adapted their behaviours, to compensate for deviations of individual players, and maintain stability in levels of team synchrony (reciprocal compensation). Specifically, they defined team configurations, based on co-positioning of players in relation

to the ball and goal, and were able to observe that certain team configurations allowed synchronisation to remain more stable than other team configurations. Moments of instability were identified, for example, when the speed of the ball passing preceded a sudden change in the team configuration and consequently disturbed team synchronisation levels. Using eco-physical variables has been used to study behaviour in several sports (Araújo et al., 2021). Eco-physical variables, capture the continuous adjustments of athletes to relevant properties of the performance environment, allowing for a theoretically-informed performance analysis. For example, in football, the eco-physical variable 'player-ball-goal angles' was used by Carrilho et al. (2020) to assess team synergies.

To conclude, this introductory chapter sets the scene for the ensuing chapters of this book which have the targeted aim of exploring different aspects of performance, learning and development of players and teams in the sport of association football/soccer, from the perspective of Ecological Dynamics. It has been several decades since a dynamical systems account of team performance in football was proposed, setting out a simple rationale explaining how an adaptive system (composed of individual players: each an adaptive system too) could engage in transactions of energy, creating information to regulate system behaviours. In the ensuing decades, an ecological dynamics framework has emerged to frame our understanding of player-environment transactions in football. This book provides a systems orientation in examining how key tenets of ecological psychology, evolutionary sciences and the complexity sciences have added to development of our understanding of how such adaptive systems function in athlete development and performance preparation for competition in the sport of football/soccer. Importantly, the same theoretical principles for understanding individual athlete development are those for understanding team development, for guiding both performance analysis and practice design. There is no *ad hoc* theory, but instead a coherent theory, that develops in strict correspondence with the phenomenon of interest, playing football.

Many of the chapters in this book will reveal how decision-making and tactical performance behaviours in football, framed by concepts in Ecological Dynamics, can be captured using eco-physical variables, encapsulating the continuous adjustments of athletes to the momentary information that emerges from their dynamic relationship within a performance

environment. Consequently, this perspective has a direct effect on how practitioners (coaches and teachers) might assess and design effective learning settings, and in a broader sense, on how they understand perception, action, and decision-making behaviours. The design of practice tasks, from an Ecological Dynamics perspective, is based on the manipulation of constraints in a performance environment. Such representative learning design fosters the athletes' ability to adapt to the dynamics of interactions with the environment, rather than rely on the rehearsal of pre-defined 'optimal' behaviours (see Chapter 8). Skilled tactical behaviours can be developed following a nonlinear three-stage model (Araújo et al., 2023). First, there is exploration to train intentions to converge towards a task goal. Second, there is discovery and then stabilisation of movement solutions, which help players to educate (train) their attention directed to sources of information that can be used to guide successful actions. Third, there is exploitation, for calibrating movements based on the detected information. Training intention, attention and calibration is a whole process nested together. The three stages are dependent on continuous behaviours and activity, and not stored as rule-like prescriptions in the individual's mind.

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