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Understanding How Athletes Learn: Integrating Skill Training Concepts, Theory and Practice from an Ecological Perspective

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Abstract

Adopting a coaching perspective centred on athlete-environment interaction, this article summarises contemporary skill training literature and theoretical principles based on Nonlinear Pedagogy (NLP) and the Constraints-Led Approach (CLA). Our analysis highlights two main issues: 1) that athletes learn by using information in a performance environment to coordinate their actions; and 2), there are implications of these ideas for training designs and for coaches, athletes and educators. Specifically, we examine various guiding ideas for: 1) training designs; 2) the role of the coach during training; and 3), the athlete-coach relationship and the learning process. These notions lead us to propose a one-page summary graphic. The article also concludes with five training principles for coaches and applied sport scientists to consider and adopt.

Key Words

Skill adaptation; Coaching; Nonlinear Pedagogy; Constraints-Led Approach; Representative learning design; Movement variability; Co-designing practice.

Introduction

'Repetition without repetition', 'train the way you play' and 'learning to learn to move' are ideas for designing practice environments that researchers, educators, coaches and athletes may encounter in their work. These concepts are important because they succinctly capture key theoretical ideas from an Ecological Dynamics rationale, Nonlinear Pedagogy (NLP) and the Constraints-Led Approach (CLA), explaining **how coaches can help athletes learn to coordinate their actions in performance environments** (eg in invasion games such as netball, hockey and rugby). Ecology is the study of the relationship between an organism and its environment. An ecological perspective in sport, therefore, is based on the idea that athlete behaviour is best understood when it emerges from the mutual relationship established between the athlete and their performance environment. This perspective for understanding sport performance has gained considerable traction in the coaching and applied sport science literature in recent years, promoting coaches' understanding of the acquisition of skill, expertise and movement coordination (for overviews see Chow, 2013; Renshaw and Chow, 2019). While many academic papers and studies explore skill acquisition training methods, bridging the gap between theory and practice sometimes tends to lag and catch up slowly. For this reason, here we provide a brief analysis of key ideas of NLP and the CLA for sport coaching and applied sport science practitioners.

Structure and purpose of the article

To begin, we provide an overview of main concepts and ideas within a NLP and the CLA. It is our goal - using a one-page summary graphic (see Figure 1) - to guide educators, coaches and athletes to better understand how these ideas link. Later in the article, academic references and knowledge sources are provided to support further understanding. Consequently, this article introduces concepts for readers to perhaps follow up by reading relevant research papers in more depth (see Table 1 and reference list).

We start by making the point that coaches and sport practitioners at all levels need a model of learning and the athlete learning process to guide their work. Here, we present an ecological perspective on skill acquisition in two parts. The first part of the article provides an ecological explanation of how athletes learn to use information in the performance environment to coordinate actions (see Part A at the top in Figure 1). The subsequent section emphasises implications of these ideas for training designs and coaching (see Part B at the bottom in Figure 1).

A key point summarised in Figure 1 is gaining an understanding of how athletes coordinate and acquire movement skills, relative to information from their surrounding performance environment. This perspective of skill acquisition in sport frames an overall approach to athlete-environment-centred coaching (ie central, red rectangle in Part B of Figure 1) with relevant pedagogical principles for: i) the designing of training activities (left section in part B of Figure 1); ii), the coach as 'Facilitator' and 'Moderator' in part B of Figure 1); and iii), the athlete-coach relationship and making sense of the athlete learning process (right section of part B in Figure 1).

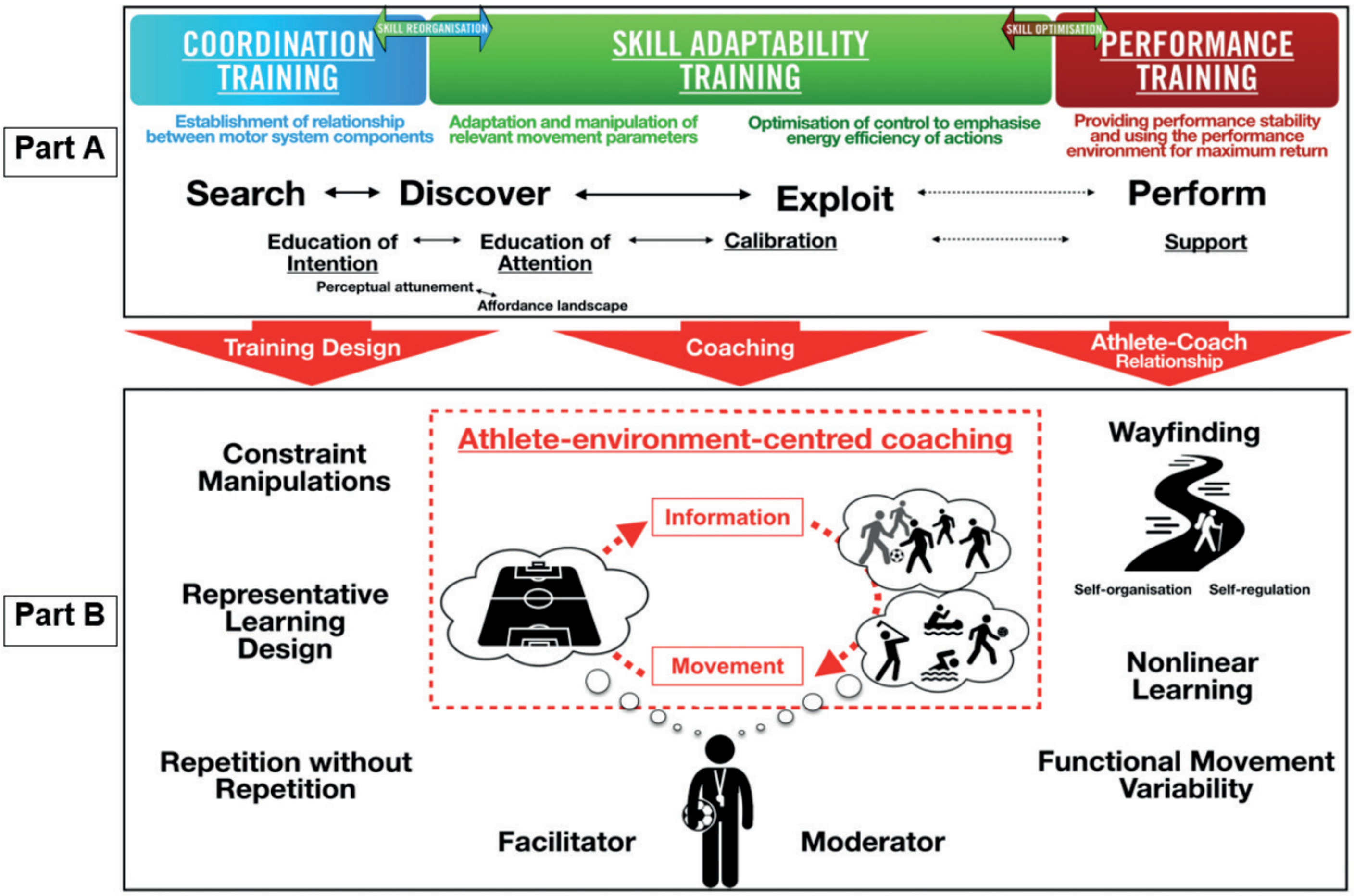

Figure 1: One-page summary to introduce key skill acquisition and motor learning principles

Table 1: Selection of references recommended for more in-depth study on the topic of contemporary skill acquisition training theory

Concept	Proposed References
'Concepts from Part A of Figure 1'	
Skill Training/Development Stages	Otte, Millar and Klatt (2019) – **Open access (online)**
Search, Discover, Exploit, Perform	Davids, Bennett and Button (2008)
	Gray (2020) – **Open access (online)**
Education of Intention, Attention and Calibration	Fajen, Riley and Turvey (2008)
	Gray (2017) – **Open access (online)**
'Concepts from Part B of Figure 1'	
Athlete-Environment-Centred Coaching	Araújo and Davids (2011) – **Open access (online)**
	Otte, Rothwell, Woods and Davids (2020c) – **Open access (online)**
Constraint Manipulations	Correia, Carvalho, Araújo, Pereira and Davids (2019)
	Gray (2019) – **Open access (online)**
Representative Learning Design	Pinder, Davids, Renshaw and Araújo (2011)
	Brackley (2017) – **Open access (online)**
Repetition Without Repetition	Ranganathan, Lee and Newell (2020) – **Open access (online)**
Coach as Facilitator	Renshaw, Davids, Newcombe and Roberts (2019)
	Woods, McKeown, Rothwell, Araújo, Robertson and Davids (2020) – **Open access (online)**
Coach as Moderator	Otte, Davids, Millar and Klatt (2020b) – **Open access (online)**
	Newell and Ranganathan (2010)
Athlete-Environment-Centred Coaching	Gray (2019) – **Open access (online)**
Wayfinding	Woods, Rudd, Robertson and Davids (2020) – **Open access (online)**
Nonlinear Learning	Chow (2013)
	Renshaw and Chow (2019)
	UK Coaching (2020) – **UK Coaching member access**
Functional Movement Variability	Button, Seifert, Chow, Araújo and Davids (2020)
	Buszard (2013) – **Open access (online)**
	Buszard (2020) – **Open access (online)**
	Seifert, Araújo, Komar and Davids (2017)

Movement Coordination and Perceptual Learning
This section addresses Part A of Figure 1. How athletes learn to coordinate and control their movement skills (sometimes called 'techniques') in sport performance environments has been studied for many years by psychologists, and movement/ coaching scientists (see Renshaw et al, 2019). Based on an ecological rationale, we would like to emphasise one key idea of this approach: **the continuous integration and interactions between athletes and their environment**. What this signifies in practice is that athletes never perform movements in isolation and there is always a performance context to consider. Their actions are continuously shaped by, for example, locations and movements of other performers, whether teammates or opponents. Influential environmental factors include weather conditions, the playing area and surface, and crowd effects. Contextual factors are exemplified by the current game state and specific competition rules, specific playing area markings, all of which continuously inform their decision-making and actions. In short, athletes do not perform in a vacuum and are always surrounded by information from the performance environment which they need to consider when organising their decisions and actions. An ecological approach, therefore, focuses on how each athlete coordinates a (sport-specific) action (eg playing a long pass behind the opponent's defence) with the perception of information from the environment surrounding them (eg a teammate running from deep into the open space behind a defender may invite a long pass into that space). In other words, athletes need to 'learn to learn to move' in specific performance contexts, highlighting the inseparability of the individual from their environment (Adolph and Hoch, 2019). So, practice designs and coaching methods must provide a context and performance background to best help learners develop relevant skills. Here, the ecological mantra of 'search, discover, exploit' may offer a starting point for coaches to grasp foundational ideas of: i) **movement coordination** by Bernstein, Newell and colleagues (see Seifert et al, 2017; Table 1); and ii), **using information to organise actions in performance and practice** by Gibson and colleagues (see Araújo and Davids, 2011; Table 1).

How can these ecological skill acquisition and practice design ideas be implemented?
Otte and colleagues (2019, 2020a) proposed a three-staged skill development framework for skill training and periodisation (ie top of Figure 1). From left to right, first, the 'Coordination Training' stage (in blue) emphasises the 'search' component of athletes establishing and stabilising the relationship between relevant motor system components (eg a hockey player coordinating various body segments to control or pass a ball). Second, the 'Skill Adaptability Training' stage (in green) focuses on the 'discover' and 'exploit' components by enhancing movement adaptations and optimising movement efficiency (eg a footballer refining coordination (in both lower limbs) to develop optimal force and acceleration when crossing a football from different areas of the field into the penalty area). Third, the 'Performance Training' stage of the framework (in red) extends to each athlete's immediate preparation for, and involvement in, competition. This final performance training stage aims to stabilise and prepare athletes on various psychological, physical, and social levels for a maximum return in a competitive event; for example, players lead their own game warm-up routine to feel comfortable and confident to play in competition. Notably it is proposed that all skill development stages work in synergy. An athlete's search for, and adaptation of, movement solutions may move back and forth between these stages throughout the learning process (see Chow et al, 2008, for a discussion). For example, athletes can hit a moving target by throwing a pass, but are challenged to make the pass when they and the target are running.

Further, in interaction with the movements, we must consider the environment and its rich information and affordances. Affordances are invitations and opportunities for action that an athlete can use in a performance environment. Many dynamic and complex sport environments are full of constantly changing possibilities for actions, such as shooting, penetrative passing, dribbling at speed or maintaining possession. Perceiving opportunities for action (eg different options for actions) is a hallmark of high skill levels, learned in practice. Fajen and colleagues (2008) and Jacobs and Michaels (2007) provided insights on perceptual learning for making decisions and coordinating actions.

In a nutshell, an athlete's search for, and discovery of, functional movements, is dependent on learning to perceive and interpret which environmental information sources to pay attention to at any moment in time. For example, while the intent to score game points may need initial training on which distances and angles are generally reasonable for shooting, the player, over time, can discover useful environmental information to guide their decision-making and actions (eg affordances such as positioning of opposition defenders, gaps between them, location of nearest teammate and the speed of the approaching ball). To enhance athlete decision-making, coaches can stretch themselves and their athletes by designing more complex practice tasks to simulate dynamic performance conditions. In this way, they can shape what athletes need to focus their attention on amongst a range of information sources. Practice tasks should constantly help athletes to become strongly attuned to the different possibilities for action (affordances) in performance situations (see Pacheco et al, 2019).

Further implications for training and coaching

Now we move to the bottom half (Part B) of Figure 1. A critical idea in an **athlete-environment-centred coaching perspective**, is understanding the coupling of environmental information and movements during practice and performance (see central, red section in Part B of Figure 1). This is an important property for training designs, coaching interventions and the development of enduring athlete-coach relationships.

Additionally, we cover aspects that span across Part B in Figure 1. On the left, three pedagogical principles for effective training designs are listed, whilst in the centre, coaches' roles are viewed as facilitators and moderators. Finally, on the right, athlete wayfinding, nonlinear learning and movement variability are listed. We explain each of these in the following sections.

Pedagogical principles for effective training designs

Designing effective training environments, as the main stimulus for learning, is important for athlete development. Practically applying theory to coaching practice, we discuss three methods for enriching training design/planning.

Constraint manipulations

Manipulating task constraints in training may be the most accessible and effective way of directing a learner to perceive and explore relevant information during performance. Particularly, understanding how to drive **athletes to search for, discover and exploit information and action possibilities** (affordances) to solve performance problems is key in training designs. Figure 2 shows three different constraints categories, originating from Newell's (1985, 1986) model of constraints on coordination: individual, task and environmental constraints (Button et al, 2020; Davids et al, 2008).

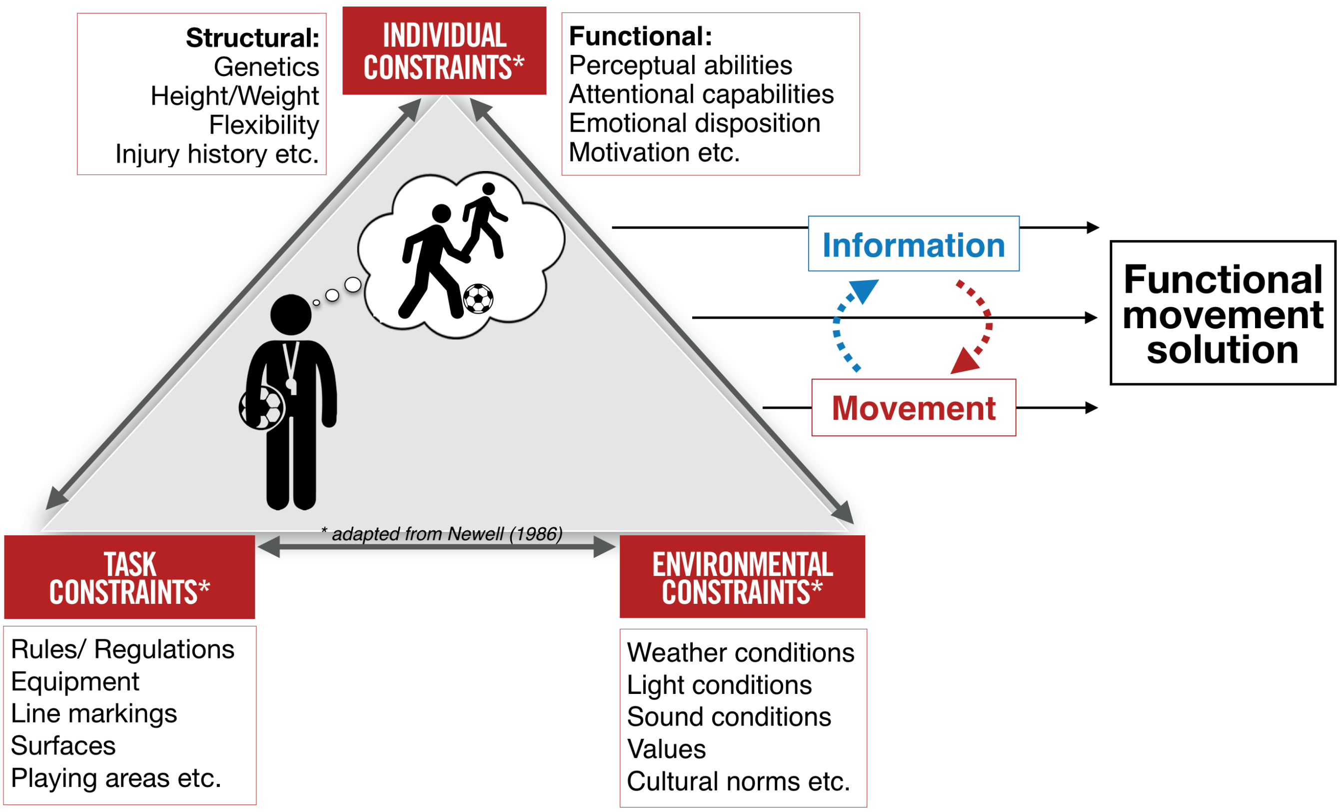

Figure 2: Three interacting constraint categories and examples to drive the coupling of information and movement (Source: adapted from Davids et al, 2008).

Bear in mind that different athletes have varying capacities (eg physical capabilities or perceptual-cognitive abilities). Further factors, such as maturation, learning, social-cultural influences or even recovery from injuries, may impact on an individual's performance and learning. In addition to changing personal differences between and within athletes, further constraints on athletes' perception, actions and performance behaviours depend on tasks designed by coaches, (eg changing playing area dimensions and numbers of players involved, or altering practice scenarios such as game scores and time available to 'chase' or 'defend' deficits). Constraints of the external environment also shape performance behaviours (eg a daytime game on natural grass at the height of summer versus a night game on artificial turf under wintry conditions). Manipulation of these three constraint categories cause any training or performance environment in sport to be constantly changing and impact athletes' perceived opportunities for action (affordances). Therefore, coaches' understanding of which constraints to manipulate in training, and when, is important for learning and development (Orth et al, 2018).

For example, which constraints may coaches manipulate in training to encourage perception, problem-solving and decision-making? One option is: **task constraints**; these, include playing time, surfaces, rules, and line markings that can be varied and adapted throughout training sessions (Correia et al, 2019). Adjusting these constraints on action may allow coaches to simplify (stabilise) tasks or increase information complexity to challenge athletes and drive skill adaptation (Otte et al, 2019). Other ways of manipulating constraints and encouraging exploration in training may involve scaling and modification of equipment, such as down-sized goals or targets, racket dimensions in tennis, and balls with different properties (mass, colour and size) (see Correia et al, 2019, for practical examples).

Representative learning design

Training designs should stimulate and challenge learners to perceive information, use affordances and solve problems that they may face in competitive performance situations. Overall, research and theory advocate the importance of exposing athletes to learning designs that represent or simulate competition conditions in order to advance perception of most relevant affordances and information (see Table 1; Pinder et al, 2011).

Representative learning design relates to the idea: **'train the way you play'**. But how do we assess the representativeness of our training designs? To answer this question, it is useful to consider recent approaches of measuring the representativeness of training. Farrow and Robertson (2017) proposed monitoring and comparison of the specificity of training to competitive performance through using wearable tracking technologies (eg player tracking devices) and observational coding to record and analyse individuals' actions. Particularly, a week-to-week comparison between training tasks and game conditions is proposed; they exemplify assessing football players' ball-passing tasks in training in terms of time for information perception (ie time players are allowed before deciding to pass a ball), pitch size (ie quarter, half or full pitch) and passing targets (ie 1v0, 2v1 or 3v3 task constraints). Additionally, while Woods and colleagues (2020c) consider the use of coaches' experiential knowledge and objective performance analysis to identify key constraints to shape representative training actions (eg time in ball possession), Krause and colleagues (2018, 2019) propose a validated practice assessment tool (ie termed RPAT). This tool offers some insightful questions, such as "is the athlete striking the ball and moving with intent appropriate to achieve the task goal?" or "does the task encourage decision making similar to what is expected during competition?" (2019; p. 40). Coaches' answers to these (and other) questions can be rated on a 1-5 scale to provide a total score (out of 70) that may be used when assessing the representativeness of training designs.

It has even been proposed that coaches and athletes could **co-design game-representative training environments together with other support staff** to facilitate individualised skill development, athlete learning and performance preparation (see Otte et al, 2020c). Outlining relevant (task and environmental) constraints and using performance analytics to support transfer of specific and varied game demands into training designs is a challenging, important task for coaches and sport scientists.

Repetition without repetition

The phrase 'repetition without repetition' was originally used in Bernstein's (1967) research on the importance of variability in movement coordination. His data showed how all goal-directed movements, even apparently stable ones (eg involved in weight lifting or archery), show some trial-to-trial variations (see Ranganathan et al, 2020). Traditional training approaches often disregard this indisputable point, instead tending to encourage the mere repetition of 'idealised' movement solutions, such as practising a golf drive on a driving range (eg Williams and Hodges, 2005). Bernstein's groundwork may help us to better understand transfer from performance, **focused less on frequently executing a single solution/technique in isolation, and more on learners being challenged to repeatedly solve performance problems in varying contexts**. This is well captured in Gray's (2020) words: "We want to teach you how to repeat a good outcome without repeating a movement because we're adding variability." For example, instead of repeatedly slalom-dribbling through a set of static poles or cones prior to shooting at goal from a predetermined position, players could be encouraged to repeatedly solve 5v3 attacking situations near goal that create/prevent different dribbling and shooting opportunities in the playing area. This practice design will help learners to repeat the attacking problem with the same outcome in mind, but the solutions to solve this problem are varied.

In summary, the concept of 'repetition without repetition' may be applied to skill training on various levels. It encourages coaches to include problems, challenges and choices for athletes in order to variably adapt movement solutions and perceive varied and relevant affordances/ opportunities for actions.

Coaches as facilitators and moderators

Effectively crafted training designs allow athletes to search for functional movement solutions. An ecological perspective on practice design guides coaches to not solve problems for athletes or to tell them how to resolve these challenges. Thus, a more hands-off coaching style is proposed (see Davids et al, 2008 and Table 1). In simple terms, the coach should not be the main problem-solver during training, constantly instructing the athlete how to complete a task. Rather, it is the coach's challenge **to place the athlete at the centre of the learning process and design the training environment around their needs**. This can be achieved by manipulating constraints and carefully guiding attention and learners' problem-solving activities. There are many excellent design examples of this ecological approach in existing sport science and pedagogy literature (eg Correia et al, 2019; Mckay and O'Connor, 2018; Woods et al, 2020a, 2020b). Aligned with manipulating task constraints during training, verbal instructions and feedback may be viewed as merely an additional tool for constraining, moderating and directing athletes' attention and search activities in practice (Newell and Ranganathan, 2010). To develop understanding, we recently proposed a framework on when and how to provide feedback and instructions to athletes (see Otte et al, 2020b). The framework proposes various feedback and instruction methods, such as task-oriented coaching, the question-and-answer approach, observational learning, using video feedback, or analogy learning. These methods are relevant to many coaching situations for helping athletes learn how to search within a practice task for relevant information and affordances/ opportunities for actions. We recommend coaches dive deeper into psychological and motor learning research to understand the 'why' behind the 'how' to (verbally) coach. For example, valuable follow-up resources include literature on: the attentional focus and motor learning (eg Wulf, 2013); explicit versus implicit learning (eg Jackson and Farrow, 2005); the theory of reinvestment (eg Masters and Maxwell, 2008); and use of coaching language and analogies (Winkelman, 2020).

Wayfinding, nonlinear learning and movement variability

The athlete-coach relationship and the coach's understanding of how individual athletes explore performance environments is a critical part of practice. From this ecological perspective, understanding how athletes learn may be supported by thinking of individuals acting as wayfinders, who "self-regulate their way through competitive performance environments" (Otte et al, 2020cd). Put simply, by placing athletes in goal-directed, representative training environments, and allowing them time and space for exploration, they can learn to explore their individualised and creative actions. This approach to learning needs to start at an early age in athlete development in order to continuously enhance the proficiency and confidence of learners to function in various sporting environments throughout their whole career (Woods et al, 2020c). The process of wayfinding challenges athletes to develop and refine decision-making, self-awareness, and engagement with various constraints of the training environment, and learn to detect most relevant information to drive their intended actions in performance (Woods et al, 2020c).

As we conclude this article, it is important to acknowledge the nonlinear nature of learning: evidence shows that individuals learn at different rates, at contrasting time scales, often achieving performance outcomes in diverse ways (see Table 1 for proposed references). This nonlinear development pathway underpins the idea that learning is not a linear and tidy process. Rather it is messy, noisy and highly variable (Davids, 2015). This ecological perspective on athlete development emphasises the importance of individualised pathways for learning (e.g. Otte et al, 2019). For example, while one athlete may just need to be given the opportunity (and the coach's patience) to

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solve a problem various times, another athlete may benefit from receiving video performance feedback and infrequent questioning to guide their search, exploration and discovery.

This nonlinear view of sports performance (eg the unpredictability of climbing, swimming and team games) could transform the culture of coaching (Otte et al, 2019). For example, coaches may need to move away from the idea of predictable technical movement rehearsal and linear progression for all athletes (eg from simple to complex throughout a session) and could consider tasks high in unpredictability to encourage athlete adaptations and exploration (Chow, 2013). In short, coaches need to **'embrace the messiness of performance'** in their practice designs, by including opportunities for exploring movement variability. Previous research shows that expert athletes actually display higher levels of variability in their actions, compared to novices, yielding enlarged movement repertoires and more functional solutions in response to changing constraints in performance (Davids et al, 2015; Seifert et al, 2013).

So, what is the main coaching implication of this perspective on movement variability? A clear shift away from coaches emphasising the reproduction of 'idealised' movement techniques is proposed. It is argued that task constraint manipulations can help learners to experience and explore movement variability and skill adaptation in training (Davids et al, 2008; Ranganathan and Newell, 2013). This idea was neatly illustrated by data of Brocken and colleagues (2020) who showed how equipment modification of hockey balls can enhance exploration and adaptability in young players' dribbling skills.

Summary

This article summarised contemporary research and skill training theory from a Nonlinear Pedagogy and the Constraints-Led Approach for coaches, athletes and educators to inform their practice (see Figure 1 and Table 1). At the outset of this article, we suggested that coaches would benefit from a model of learning and the athlete learning process to guide their work. With this in mind, we sought to: i) sensitise coaches and educators towards considering the wider context of nonlinear athlete development; ii), develop coaches' understanding of the importance of integrating environmental information and athlete movements in training; and iii), highlight the individuality of athletes and the athlete-coach relationship, including coaching approaches impacting the co-design of training tasks.

We conclude by proposing five guiding training principles:

1. **The training design is the main 'stimulus' for athlete learning** – Consider co-designing training together with the athlete(s). They understand their needs well and co-designing practice tasks could deeply engage them in performance preparation and their continued development.
2. **Train the way you play** – The context to practice and training should be representative of performance; avoid skills practice in isolation and keep information and movements coupled. Training designs should, ultimately, seek to challenge athletes as they may be challenged in different phases of competition environments.
3. **'Repetition without repetition' in training** – Requires athletes to repeatedly solve problems that they may face in competition, as opposed to rehearsing a single technical movement solution in isolated drills.
4. **Encourage exploration and movement variability in training** – Related to point 3, help athletes learn that the same performance outcome or goal can be achieved in various ways, depending on the constraints faced.
5. **Athletes are the problem-solvers** – Remember: the coach is not the 'solver of problems' for athletes and instead guides, facilitates and moderates the individual to enjoy facing challenges, resolve problems, and take responsibility by making choices and decisions.

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