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Insights from Ecological Psychology and Dynamical Systems Theory Can Underpin a Philosophy of Coaching

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Abstract

The aim of this paper is to show how principles of ecological psychology and dynamical systems theory can underpin a philosophy of coaching practice in a nonlinear pedagogy. Nonlinear pedagogy is based on a view of the human movement system as a nonlinear dynamical system. We demonstrate how this perspective of the human movement system can aid understanding of skill acquisition processes and underpin practice for sports coaches. We provide a description of nonlinear pedagogy followed by a consideration of some of the fundamental principles of ecological psychology and dynamical systems theory that underpin it as a coaching philosophy. We illustrate how each principle impacts on nonlinear pedagogical coaching practice, demonstrating how each principle can substantiate a framework for the coaching process.

Introduction

Recent discussion in the Physical Education literature has focused on the need to base pedagogical practice on a sound theoretical model of the learner and the learning process (Renshaw, Davids, Chow, & Hammond, in review). Although teaching is a well established profession with a sound tradition of formal training and established pedagogical practices, there has been some criticism that practice is often not based on a theoretical model of how learners actually learn (K.M. Newell & Rovegno, 1990). In contrast, sports coaching is less established and the majority of practitioners at participation level are volunteers who are often ex-performers and who have learned their craft via practitioner experience (Lyle, 2002). In this more performance-oriented learning environment, coaching practice is even less likely to be based on theory. In fact the development of coaching as a profession has been hindered by the cult of 'big' personalities (Carter, 2006), leading to an emphasis on 'qualities' of individual coaches and 'coaching style' rather than on the coaching processes that ultimately determine the effectiveness of coaching practice. However, Lyle (2002) argued that there is little empirical evidence to suggest that one coaching style is more efficacious than another and that a 'style' still has to have 'substance'. For long-term, programmatic development of athletes there needs to be an underlying theory that insulates the coach from idiosyncratic coaching fads and fancies and a resort to 'recipe book' coaching. It has been suggested that all coaches need to base their practice on a philosophy of coaching otherwise they will lack direction and succumb to external pressures (Lyle, 2002; Martens, 2004). The quest for a guiding theoretical framework will provide a philosophical approach that is evidence-based, focusing on mechanism and not operational issues. A coaching philosophy should provide a set of guiding principles for coaching practice, while at the same time identifying the major beliefs or principles that help achieve coaching objectives (Lyle, 2002; Martens, 2004). The quest for a theory-based coaching philosophy is also needed to impact on coach education programmes. Since coaches rely on their education and experience to be effective (Feltz, Chase, Moritz, & Sullivan, 1999), it is essential that coach education provides a principled theoretical base on which coaching practitioners can build their own underpinning philosophy .

In other papers (Renshaw et al., in review) we have discussed the need for motor learning specialists and pedagogues to develop a much closer relationship. We have provided an overview of motor learning emanating from *the constraints-led perspective*, demonstrating how it can substantiate a platform for a new pedagogical framework: nonlinear pedagogy (e.g., Chow et al., 2006, Chow et al., 2007). In this previous work we showed how a nonlinear pedagogical framework, emanating from concepts in dynamical systems theory, may provide the basis for a model to determine how the popular teaching Games for Understanding approach to teaching games (TGfU) can be implemented by educators, leading to effective motor learning. There have been numerous papers that have considered the theoretical basis of the constraints-led approach and its roots in ecological psychology and dynamical systems theory (Araújo, Bennett, Button, & Chapman, 2004; Davids, Button, Araújo, Renshaw, & Hristovski, 2006)(e.g., Araújo et al., 2004; Davids at al., 2006). The application of insights from a constraints-led perspective is ongoing and there is a need for further understanding of the key theoretical concepts in order to help coaching practitioners implement these ideas in their own practice. The aim of this paper is to show how key principles of ecological psychology and dynamical systems theory can underpin a philosophy of coaching practice based on nonlinear pedagogical principles. We will demonstrate how a nonlinear approach can underpin practice for all coaches. To achieve this aim a brief description of nonlinear pedagogy will be provided followed by a consideration of some of the fundamental principles of ecological psychology and dynamical systems theory. We discuss how each principle impacts on nonlinear pedagogical coaching practice. We propose how these overarching principles can act as the cement holding together the building blocks of the coaching process (Lyle, 2002).

What is Nonlinear Pedagogy?

In simple terms, nonlinear pedagogy is 'application of the concepts and tools of nonlinear dynamics' to coaching practice (Chow et al., 2006), p.72). Nonlinear pedagogy is predicated on a view of the learner as a human movement system which is inherently nonlinear in character. In this respect, the nonlinear dynamical movement system is considered to show the same characteristics that other nonlinear dynamical systems in nature have demonstrated (Kelso, 1995) e.g., openness to surrounding information flows, capacity for self-organisation, stabilities and instabilities, capacity for transitions in states of order, especially in the region of criticality and much more (Davids, Bennett, & Newell, 2006). In particular it is important to identify the key constraints that impinge on any specialized nonlinear dynamical system in nature in order to understand emergent properties of such systems (K.M. Newell, 1986). In nature, different nonlinear dynamical systems satisfy a range of constraints as behaviour emerges from them (Davids et al., 2007). The basis of nonlinear pedagogy, therefore, involves the manipulation of key task constraints on learners to facilitate the emergence of functional movement patterns and decision-making behaviours in different sports and physical activities (Chow et al., 2006). There are a number of basic concepts of dynamical systems theory and ecological psychology that need to be understood before a coach can implement this constraint-led approach in a nonlinear pedagogy. These key ideas are elucidated in the remaining sections of this paper.

Brief Explanation and Implications of Assumptions for Nonlinear Pedagogical Coaching Practice:

1. The mutuality of the performer and the environment

A key tenet of ecological psychology is the mutuality of the individual and his/her environment. In this explanation, the environment refers to the surroundings of animals that perceive and behave (J. J. Gibson, 1986). The important point is that individuals cannot be understood without reference to their specific environments. In team sports, the environment could consist of other individuals such as team mates and opponents, as well as the playing surfaces and inanimate objects that define each specific performance context (such as an ice rink in skating, parallel bars in gymnastics or goalposts and pitch markings in the football codes). For an individual to engage effectively with other individuals, events, surfaces and objects in his/her performance environment he/she needs to detect the key *affordances* within that location. An affordance refers to a property of the environment which can be detected as information to support an action, and which is related to an individual's ability to use it (E. J. Gibson & Pick, 2000). For example, an unmarked team mate affords the opportunity to make a pass for a player with the ball in team sports, while the surface of the ice in a rink affords sliding across on the blades of a skate and for a gymnast a three-inch balance beam affords performing back flips. Although these affordances are always available for actions by an individual athlete, their presence does not mean that the detection and learning of affordances are automatic processes. In fact, some affordances will require significant periods of exploration, practice and time for detection and use to support action (E. J. Gibson & Pick, 2000). This point has important implications for sports coaches who are attempting to facilitate the development of sporting excellence. It highlights the need for coaches to accurately sample the information in the performance environment (Davids et al., 2006) and to create practice activities that provide athletes with many opportunities to become attuned to the specifying information sources available in that environment (Beek, Jacobs, Daffertshoffer, & Huys, 2003). Specifying information can be classified as information that acts to constrain movements, whereas non-specifying information is information that is less relevant (Jacobs & Michaels, 2002). As a result of practice, a process of education of attention leads to learners shifting from picking up non-specifying variables and converge on specifying variables (Jacobs & Michaels, 2002). Consequently, performance environments need to be carefully replicated during practice and training so that athletes can learn to detect affordances for action and to use these sources of information to regulate their movements. A key question for the coach is to ask herself/himself: are my practice sessions representative of the performance environment? In ecological psychology, representative task design underpins successful identification of information for action in the Brunswikian tradition. For Brunswick, representativeness refers to the generalisability of task constraints in a specific research context in relation to constraints outside the experimental settings (Davids, Araújo, Button, & Renshaw, 2007).For coaches the experimental setting equates to practice environments and coaches need to accurately sample the environmental conditions of practice to ensure congruence with the performance environment in which the movements will be implemented (Davids, Araújo et al., 2007). Ensuring the design of representative practice tasks requires the coach needs to have an implicit understanding of the interaction between key individual, task and environmental constraints of specific sports performances (Davids, Chow, & Shuttleworth, 2005).

The importance of coaches creating representative practice environments can be clearly illustrated by looking at how coaches structure practice when coaching children. In children's sport, the potential movement solutions available to children are strongly determined by the fit between their environment and their current stage of development. For example, a young basketball player who is required to take a set shot to a 10 foot hoop with a full size ball will result in a movement solution that does not reflect that of an adult shooter.

This practical example highlights an interesting dilemma for coaches and administrators about when it is most appropriate to make children's sport representative of the 'adult' versions of sports and when to attempt to scale equipment and performance environments in relation to the developmental stage of the performer. If coaches believe that it is important for children to replicate movements of adults, then it is important to scale equipment and task environments to the developmental stage of the learner (as opposed to chronological age). However, children are continually learning as they develop and if successful performance can be achieved in a number of ways then the coach may choose not to manipulate the task constraints and require children to play to adult rules. Although time and space do not allow a detailed discussion of these issues, it is interesting to note that many sports administrators are developing scaled down versions of adult sports. The adoption of these modifications to the sporting activities of children is supported by many sound motor learning and psychological principles. There is also some evidence that older children might benefit from some early exposure to adult sport in the development of their expertise (Abernethy, Côté, & Baker, 2002 ; Berry & Abernethy, 2003). Nevertheless, it is clear that for motor learning to occur, representative task design requires -scaling of equipment, facilities and performance locations, so that the affordances present for detection in practice settings are congruous with those available in performance environments.

2. Perception and Action are coupled.

In Gibson's (1979) ecological psychology the concept of direct perception signifies the tight coupling of perception and action systems in individuals (Savelsbergh, Davids, Van Der Kamp, & Bennett, 2003). In essence, information drives movements, but movements also influence what information can be picked up by performers/learners. This principle has profound implications for the design of coaching practice. Essential to the learning process is the need for athletes to be provided with opportunities to learn to perceive the key specifying information sources within a performance environment in order that they are able to produce functional movement solutions. This point can be illustrated by observing what happens when coaches provide practice opportunities that do not include such specifying information. In a study of cricket batting, we demonstrated that batting against bowling machines as opposed to real bowlers led to a re-organisation of the timing and co-ordination of a forward defensive shot (Renshaw, Oldham, Davids, & Golds, 2007) and did not facilitate opportunities for batters to learn to utilize information from the bowler's actions-a key component of expert batting performance (Müller, Abernethy, & Farrow, 2006). These findings illustrated the need for practice task constraints to include meaningful opportunities for learners to identify and use affordances for action from the movements of key individuals in sport. The principle of perception-action coupling suggests that coaches should ensure that practice tasks are designed to keep key information sources and actions together. This principle can be violated in practice tasks such as batting against a bowling machine or when long jumpers practice run-throughs without jumping. In this regard it is important for coaches to use a strategy of task simplification rather than task decomposition when designing practice sessions (Davids, Button, & Bennett, 2007). Task simplification means that the information-movement couplings utilised during performance are preserved by requiring learners to practice in simulate natural performance conditions, but key performance variables such as velocity of balls and opponents, number of players in the game and size of playing areas are reduced to simplify the task. For example, in badminton the coach may increase the height of the net to slow the game down. In long jumping, the athlete would run up and jump from a shorter run up, rather than using a decomposition strategy practicing the run-up separately to the jump. In team games, tasks can be simplified by reducing the numbers in teams or by reducing the size of the playing area rather than reducing skills to practice in static drill activities that are not relevant to game situations. In summary, the key point of task simplification is that it enables learners to practice with all key information sources present. As Gibson (1986) reminds us, specific *movements* of the performer and/or objects to be acted upon have a significant role in determining what information-movement-couplings are developed. In essence, practice simplification enables dynamic 'perceiving and acting' as a circularly casual process involving (a) forces giving rise to flows/forms/times and (b) flows/forms/times constraining or giving rise to forces' (Turvey & Carello, 1986).

3. Performance emerges as a consequence of the interaction of individual (and team) constraints: Self Organisation under constraints

A key principle of dynamical systems theory is that behaviour emerges through a process of self organisation shaped by the interacting constraints of the individual, task and environment (Davids, Button et al., 2007). If these constraints stay the same, then stable movement patterns may be developed. However, changes in constraints lead to instabilities in learners and result in the re-organisation of the system, with new patterns of behaviour emerging. From this viewpoint, instabilities are an important part of the learning process. In sport performance the coach is faced with constantly changing constraints due to individual development (i.e. growth and maturation, ageing, changes in fitness, psychological variations, etc), dynamic task constraints (e.g., performing a task under a variety of conditions due to differences in locations, weather, performance environments, etc) and environmental conditions (e.g., altitude, travel, social and cultural contexts of performance). Some of these changes may be within his/her control, whereas others could be uncontrolled processes due to factors such as growth and maturation. For example, individual constraints can be classed as structural constraints such as height, weight, muscle mass or leg length) or functional constraints such as motivation, memory, or attentional focus (Haywood & Getchell, 2005). Coaches need an understanding of how structural or functional constraints might be shaping the observed behaviours of learners/performers. For example, when coaching children the structural constraints of the size a child's hand and grip strength may be a determining factor in the quality of a pass in basketball, rather than poor technique. Or, at a different level of development, an ageing adult's muscle stiffness may be responsible for the manner in which a flic-flac is performed towards the end of a routine, rather than lack of skill. A key to understanding the impact of structural constraints on performance is identifying how specific sub-systems can act as rate limiters on the emergence of specific movement solutions. As sub-systems of the body do not develop at the same rate, skills may only emerge when all the relevant sub-systems have reached a critical level (Thelen, 1995). Thus, the slow development of one sub-system can act as a rate limiter. In child development, achievement of a specific level of muscular strength is said to be a rate limiter for the emergence of walking (Haywood & Getchell, 2005). Clearly, knowledge of potential rate limiters on performance is important for coaches as they will determine the emergence of specific movements or game strategies. For example, in the pommel horse in gymnastics the coach needs to understand that upper body strength acts a rate limiter on the introduction of double leg circles. For an older individual, poor mobility around the shoulder joint may impact on overarm throwing technique, while in team sports, the knowledge base of individuals can act as a rate limiter on decision-making (Haywood &

Getchell, 2005). To conclude this section, as an aside, an interesting idea would be to examine how cultural and physical environments can act as rate limiters on the development of performance.

Sport performance has also been investigated as context in which self-organisation processes may exist. For example, performance in specific sports has recently been modeled as a self-organising system (McGarry, Anderson, Wallace, Hughes, & Franks, 2002). This argument was demonstrated by empirical data in the racket sport of squash and the team sport of soccer showing that patterns of organisation in these sports display characteristics common to dynamical systems. For example, in squash match-play, it was observed that player movement patterns went through stable phases such as long rallies up and down the backhand wall before a perturbation (e.g., a well-placed shot that extended the opponent, or a loose shot to open court that allowed the opponent to capitalize on the mistake) led to a period of instability, ending with the regaining of a stable state or the termination of the rally (McGarry et al., 2002).
Capturing sport performance in concepts from dynamical systems theory may be useful for coaches and players in identifying the key factors that cause perturbations in games. It can lead to questions of interest, such as: How did the athlete react to the perturbation? What was the effect of the perturbation on the stability of the system? (McGarry et al., 2002).

On a more general level the concept of self organisation has important implications for coaching practice and supports the use of a more ‘hands-off’ coaching style where coaches can shape behaviour by designing practice tasks constraints that facilitate the emergence of functional movement solutions (Davids, Button et al., 2007) . To illustrate this point, we will provide examples of how gymnastics coaches can use task constraints to shape behaviour to support more effective performance in a floor activity (the cartwheel) and a pommel horse activity (double leg circles). A common error in performing the cartwheel is for the gymnast to 'pike' at the hips. This means that the performer fails to keep a linear shape between the hands and the toes as he/she rotates. The common approach to solve this problem is to point out the error and use instructions to correct it. An alternative approach is to exploit self-organisation processes in learners by introducing a constraint on performance. For example, coaches could place two crash mats in parallel and require the gymnast to cartwheel between them. In this approach, as the performer gains feedback from the legs touching the mats and becomes better at keeping the straight line body position, the mats are brought closer together. This approach reduces the need to provide verbal instructions to the performer since task-related feedback is constantly available from the mat positions relative to the learner's legs as the cartwheel is performed. In our second task, the young gymnast who struggles to perform two legged circles is helped to overcome this problem by coaches placing both feet in a bucket which is suspended from a beam. The use of equipment in both examples shows how coaches could introduce physical constraints on learners to harness the inherent capacity for self-organisation that all humans demonstrate.

4. Performance development is a nonlinear process.

Traditional approaches to explain development adopted a neural-maturation perspective. Form this viewpoint; achievements in motor behaviour were believed to occur at predetermined ages, with movement patterns emerging as a result of cerebral maturation in an orderly genetic sequence (Savelsbergh et al., 2003). The key contribution of this approach was the idea of motor milestones. Although this approach has lost favour in the field due to it uni-dimensionality, its influence can still be seen in linear models of talent development, where talent identification is based on chronological age leading to those children born earlier in the year and who are consequently biologically mature being favoured in selection for elite representative squads in many sports (Côté, Baker, & Abernethy, 2007). In contrast, recent research has demonstrated that talent development is (a) a nonlinear process that exhibits many of the features of open dynamical systems (Abbott, Button, Pepping, & Collins, 2005), (b) that shifts in performance occur in a discontinuous manner (Thelen, 1989) and (b) that emergence of expertise is a multidimensional and multiplicative developmental process (Simonton, 1999). The model presented by Simonton highlighted that interaction of essential components (which are sport specific) underpinning skilled performance is deemed to be essential to the development of expertise and that late emergence of any one factor can act as a rate limiter on performance. Theoretically, Simonton's ideas on talent identification provide a strong link with contemporary thinking in motor development and highlights that behaviour is an emergent property of a confluence of factors (Thelen, 1995).

The nonlinear nature of performance development has a number of practical implications for coaches. First, it highlights the need to recognise that "children grow at different rates at different ages and different children also develop at different rates" (Aldridge, 1993). Second, individual sub-system development needs to be monitored, including factors such the onset of growth spurts and changes in body proportions. The sudden changes incurred by growth spurts may require re-scaling of equipment used by learners or of practice environments (e.g., practice pitch or court dimensions). Third, careful observation is needed of how exposure to new environments (e.g., changes in game formats as players progress through age group sport) and new performance demands (e.g., playing representative sport) may act to perturb the stable movement patterns displayed by sports performers. Finally, the coach needs to understand the interacting constraints on performance and learn how to carefully manipulate them to create changes in performance, based on recognition of the rate limiters that are shaping the current behavioural repertoire of each learner.

5. Variability is essential to the development of performance.

Variability within individual movement patterns has traditionally been viewed negatively, since a common goal for many coaches is the acquisition of an ‘ideal’ technique as a template for performance success. In fact, much traditional practice is based around the need for performers to have acquired the 'correct' technique before being exposed to the *real* game. However, there is now a large body of research that demonstrates that learners can achieve task outcomes by using different co-ordination patterns and that experts often display more variability within their movement patterns than less skilled individuals (Davids et al., 2006).The concept of degeneracy, which refers to the capability of structurally distinct parts of complex movement systems to achieve different outcomes in varying contexts (Davids, Button et al., 2007) supports the efficacy of performers developing more functionally variable movement patterns. In fact, functional variability is essential so that skilled performers can adapt to subtle changes in initial conditions at the start of the movement or to ongoing changes in the performance environment. For example, long jump competitions take place in environments that require the jumper to undertake 6 maximal efforts in environmental conditions that may vary over the time frame of the competition. Despite this many coaches require athletes to practice in sterile conditions and undertake decomposed practice tasks such as run-throughs in order to provide what they believe is the best chance for their athletes to standardise their run-up. However, it is now well established that Olympic standard long jumpers are not capable of placing their feet in the same place for every run-up and actually adjust their step patterns as they approach the take-off board (Hay, 1988; Montagne, Cornus, Glize, Quaine, & Laurent, 2000). In actual fact, during a competition the jumper may need to make adjustments for changes in individual constraints such as fatigue and psychological stress as well as changes in environmental conditions such as run-up surfaces and changes in wind speed or direction. The implication is that rather than reduce variability, the coach should actually increase the variability in practice conditions so that the athlete develops adaptability and flexibility to cope with changing task constraints (Edelman & Gally, 2001).

In dynamical systems, variability is also seen as an essential feature for creating instabilities leading to phase transitions. This idea will be discussed in more detail in the section 8, where we consider the role of the coach in balancing the need for coaching practice that results in stable behaviours versus the need to create instabilities that lead to the emergence of new co-ordination patterns.

6. The individual is the focus

In nonlinear pedagogy the aim is to keep the individual at the centre of the learning process.. How can this aim be achieved in practice? The first requirement for the coach is to identify the intrinsic dynamics of the individual learner or of each member of a squad or team. Intrinsic dynamics refer to “the set of movement capabilities that people bring with them when learning a new skill”(Thelen, 1995). A person’s intrinsic dynamics are unique and shaped by genetic factors, previous experiences and both physical and cultural environmental influences (Davids, Glazier, Araujo, & Bartlett, 2003). Consequently, the coach needs to identify previous sport specific experiences as well as previous participation in tasks that may act to facilitate skill development due to cooperation of the movement dynamics (e.g., throwing balls and overhead shots in badminton) or where previous tasks may result in learning difficulties due to competing movement dynamics (e.g., squash shot and tennis shots). More detailed assessment of performer’s intrinsic dynamics should attempt to identify what the emergent constraints are on current performance for each individual. In practice, the coach may be able to group individuals into sub-groups which possess similar emergent constraints and thus manipulate task constraints to provide learning experiences that are optimal for all individuals in the group. One way of doing this would be to categorise athletes in stages according to Newell’s (1985) model of motor learning (e.g. co-ordination, control and skill). An individual at the co-ordination level would be attempting to assemble a suitable co-ordination pattern to achieve a task goal. This performer would often solve the problem by freezing the mechanical degrees of freedom of the body (Bernstein, 1967). At the control level, the performer would have successfully developed a co-ordinated pattern and is now attempting to develop a tighter fit between the assembled co-ordinated structure and the environment (Davids, Button et al., 2007). This is often typified by a greater release of the degrees of freedom enabling more efficient movement patterns. An individual at stage three in Newell's model is able to optimize performance by exploiting the degrees of freedom demonstrating instantaneous adaptability in their movements to satisfy changing task constraints (Davids, Button et al., 2007). In summary, coaches need to realise that one size does not fit all in terms of practice activities and understanding intrinsic dynamics of each individual provides the basis for programmes that truly individualise the coaching process even in team or squad coaching.

7. The team as an open dynamical system.

As we noted earlier, recent research in dynamic pattern formation in game play has supported the view that one can observe principles of dynamical systems in sport contests at an individual level e.g., squash (McGarry & Franks, 1994; McGarry & Franks, 1996a; McGarry & Franks, 1996b ; McGarry, Khan, & Franks, 1999) and tennis (Palut & Zanone, 2005). There also appears strong support in the literature for considering the possibility of behaviours in team sports as a collective of dynamical interactions (Araújo et al., 2004; McGarry, 2006 ; McGarry et al., 2002; Passos, Araújo, Davids, Gouveia, & Serpa, 2006 ; Schmidt, O'Brien, & Sysko, 1999). In these studies, performer interactions in different sub-phases of individual sports and team games can be modelled as pattern forming dynamics in complex systems (Passos et al., 2008). This is possible because, from a dynamical systems theoretical perspective, different levels/scales of analysis have been recognized as highly integrated due to the fractal nature of complex systems. The fractal nature of complex systems pre-disposes them to self-similarity, meaning that the same principles can be used to describe the properties and behaviours observed at different levels or scales of the system (Kauffman, 1993; Kelso, 1995). From this theoretical standpoint, an individual player or a complete team or a complete team game could each be described as a dynamical system because each system is "one in which regularity self-organizes from within as a result of information exchanges that occur both inside and outside the system (i.e. among the parts that comprise the system, and between the system and its surrounding constraints, respectively) (McGarry & Franks, 2007, p. 48).

According to this viewpoint, behaviour emerges in such complex systems as spontaneous patterns are formed from the interactions of individuals in the team game. This rationale signifies that there is no hierarchical control involved in the emergent behaviour of team games as complex systems (for theoretical overviews see Kelso, 1995; Kauffmann, 1995). For example, Passos et al.'s (2006) study investigating regions of 'self-organising criticality' in rugby dyads (i.e., during 1 v 1 interpersonal interactions), revealed that within a critical period (interpersonal distance) of 4 meters between an attacker and defender, system stability was most open to influence for stabilisation or de-stabilisation, if the relative velocity of both players was >4m/s (favouring the attacker) or <1m/s (favouring the defender). Their findings suggested that control parameters can be nested within other control parameters within the same space-time dimension. This mutuality between the attacker and defender implies that coaches should maintain relevant perception-action couplings in practice and encourage active player exploration in and around critical regions of player interactions. Making information available or directing players toward the relevant information related to structural re-organisation of interpersonal interactions is a most important part of a team's learning process particularly when dimensionality (or structural complexity) of the system increases.

To improve decision making in team games, training sessions should aim to attune the interaction that a player has with the performance environment, especially the actions of 'significant other' players. It is a clear misconception to equate the concept of 'self-organisation' in the interactions of team games performers with the strategy of merely allowing players to 'play the game' during practice. The nature of practice proposed in our paper is based on a rigorous process of manipulating specific task constraints, such as rules of practice games and activities, number of players involved in the task, practice area dimensions, instructional constraints, task goals, and equipment, for each individual learner. This point was highlighted over a decade ago by Handford et al. (1997). However, an important point that was emphasized in the work of (Passos et al., 2006) on team games is that, the practice tasks designed in training cannot be de-contextualized from the principles of the team game, which implies an accurate systematization of planning procedures by coaches of team games. Coaching sessions should provide a way of players engaging with the environment in developing his/her own tools to resolve the tactical issues that arise in competitive settings (Passos, Araújo, Davids, & Shuttleworth, in press). A suitable way to achieve this goal is through designing practice tasks that include plenty of variability to simulate dynamic competitive performance contexts. Confronting players with variability in practice is an important aspect of nonlinear pedagogy, recognising the need to create practice environments for individuals that allow them to seek unique performance solutions (Chow et al., 2006). Nonlinear pedagogy proposes that task constraints manipulations must be undertaken in a systematic and controlled fashion in order to ensure that the practice tasks designed by coaches are representative of competitive settings. From this theoretical viewpoint, manipulation of tasks constraints does not necessarily mean increasing the difficulty of a practice environment in a linear fashion, but rather it signifies the importance of guiding individual players to seek optimal solutions for satisfying the current unique constraints impinging upon him/her.

Coaches could ensure this process by including within the practice task constraints relevant information from team mates and opponents, as well as boundary markings, goals and pitch surface. In other words, all the tasks in a training session should aim to attune key perception-actions couplings in performers. To achieve this aim, the information available to be actively explored by players during practice must closely resemble the same task and environmental constraints faced in competitive settings. Coordinating and controlling one's own movements relative to the changing dynamics of the ball and player movement (information) highlights the very nature of the problem faced by players and teams when learning to exploit self-organisation processes to form a coordinated unit. Coaches often decompose and/or progress team practices from the level of a sub-system comprising few players (Araújo et al., 2004) to a larger system that comprises many players without understanding of the important principles that underpin effective practice. During the learning process, specific information for action can often be either lost or under-utilised due to an overemphasis on structuring the system in a 'closed' manner. This process normally occurs at the expense of players not being able to pick up the changing information required for maintaining system stability~instability. During these critical self-organising periods sub-system flexibility is important in order to adapt to changes in information flow. For example, in team games, the dynamic patterns emerging within and around the attacker-defender dyad become increasingly important during this period. The attacking system, for example, may undergo a phase transition to successfully exploit the emerging properties emanating from the resulting de-stabilisation of the defensive system. The attacking support structure may need to quickly re-organise to fully exploit the chaotic nature of the defence. The ability of the system to effectively re-organise as a result of a changing environment becomes a key characteristic in skilled team game performance.

Providing opportunities for a system to organise itself in an ‘open’ manner by carefully manipulating the environmental information becomes a key strategy in practice. This strategy provides a system with relevant information for structuring it’s re-organisation through carefully manipulating the environment in a simple but deliberate manner. An ecological approach to practice which has been previously proposed is ‘task simplification’ (Davids, Button & Bennett 2007). This method of practice both supports and maintains the perception-action link while players learn to successfully transfer and adapt structures into dynamic game situations. The role of the coach is to objectively view system behaviour and to decide upon the appropriate complexity with which the system must successfully self-organise itself and to regulate this feature along a stability~instability continuum. This scaling process between the two opposing systems should be continually adapted by the coach until the learning system can effectively self-organise under sudden environmental changes and varying levels of complexity. This form of practice in nonlinear pedagogy, which incorporates ‘repetition without repetition’ (Bernstein, 1967), has been described as a process by which the learning system does not repeatedly practice the same solution to a problem but instead continually searches for new solutions to the same problem.

8. Coaching is a balance between maintaining stability versus creating instabilities

As every coach knows, coaching is often a balancing act between protecting the confidence of athletes by providing environments that enable athletes to be successful versus risking the loss of existing confidence levels by exposing athletes to more demanding practice tasks or to more skilled opponents. This dilemma is an interesting one in relation to maintaining stability in performance by allowing athletes to exploit their current information-movement couplings or by creating instabilities that force the learner to undertake further exploration and search the perceptual-motor workspace for additional information that can be used to guide actions (J. J. Gibson, 1986). From a dynamical systems perspective, instabilities are useful in that they can lead to re-organisation of the system. From a coaching perspective, deliberately creating instability is useful in that it can prevent performance plateauing due to the movement system being trapped in a deep, stable attractor state (Davids, Button et al., 2007). Similarly, perturbing a system is a useful strategy when attempting to modify the technique of experienced performers who have well-established co-ordination patterns. When deliberately creating instabilities, coaches need to help athletes come to terms with the effects that this will have on their performance. Effectively, attempting to create a phase transition will lead to high levels of non-functional variability that will initially lead to lower levels of performance. It is worth noting that although this variability is not functional in the sense that it does not subserve current performance, it is an essential component of the transition to a more effective co-ordination pattern. When creating instability it is essential that coaches seek to understand and support the potential psychological impact on the athlete and to decide if the potential loss of confidence might impact on motivation and performance.

In summary, coaches should be very careful in providing too much stability in the coaching progress, as this can lead to a reliance on non-specifying information sources that would limit success in the future. For example, in junior singles badminton a high serve that only reaches the back double service line may afford the strong player the opportunity to smash to win the rally. However, if playing against an older, bigger opponent who can cover more of the court, the same serve may result in the opponent picking off the smash with an easy block to the net. Practically, coaches need to provide learning opportunities that expose individuals to as much variety as possible thus forcing the ‘system’ to explore its boundaries. Sticking with racket games, if we take the example of a tennis player, coaches should require players to practice and compete on indoor surfaces, clay, synthetic or grass, against left handed and right handed opponents who adopt various tactical approaches such as serve and volleying or baseline rallying. To finish this section, one cautionary note worth mentioning is that coaches might choose to provide stability in the immediate lead up to major events in order to maintain or build the confidence of performers.

9. Co-adaptive moves: Implications for practice

In previous sections we have provided examples to show that games demonstrate principles of dynamical systems. In this section we will expand on this point and illustrate how the processes of system co-adaptation (Kauffman, 1993) are a crucial consideration in designing effective coaching programmes. Kauffman's (1993) explanation of change in evolutionary systems discussed how the interactions between components of complex systems evolved as a consequence of individual agents co-adapting their actions. That is agents functioning as part of a larger system (e.g., predator and prey in nature) co-adapted to small but important changes in each other's structure and function. Although these ideas originated in an explanation of evolutionary processes, Kauffmann (1993) made it clear that co-adaptation could occur across different timescales such as that of learning. Nonlinear pedagogy advocates the concept of co-adaptation in learning in sport. For example, in the critical dyad of defender and attacker in soccer the actions of the attacker and defender are systematically related and their intentions do not make sense if separated from each other's actions (Passos et al., in press). The actions and decisions made by the protagonists in this dyadic system are externally regulated by first and second order contextual constraints (Juarrero, 1999). In our example, first order constraints include performance area dimensions, inter-personal distance between players, position on field, and rules of the game. Second order constraints, relate to the interactions of social constraints and emphasise how changes in the interactions between the two individuals in the system can lead to the de-stabilising of current system order and the emergence of a new state of order (e.g., the attacker dribbles past the defender). An important finding by Passos et al. (2008) who explored these issues in rugby union, demonstrates that an important consideration when assessing the decisions made by defenders and attackers is to take into account the initial conditions, as slight differences in performance contexts can lead to substantial differences in subsequent behaviour. Referring back to our example in rugby union, the position on the field and state of the game would have a significant impact that determines whether the defender attempted to win the ball back by pressuring the attacker or if he/she would try to conserve system stability by maintaining current inter-personal distance.

The key message from this section is that coaches need to understand that in complex adaptive systems such as team games, due to the emergent nature of information used to support decision-making and action there is no one optimal decision that can be determined in advance, as it may be difficult to predict or prescribe large sequences of play (Passos et al., 2008). Coaches should avoid attempting to 'control the uncontrollable' by designing drills that limit decision making and actions of performers. In fact, training programmes based on a sound understanding of the primary and secondary constraints that shape system attractors in performance contexts should be developed. Additionally, high levels of variability in task demands should be encouraged enabling individuals to become more adaptable performers because they can learn to make decisions in representative practice.

10. Encouraging creativity in learning and performance

Despite the continued debate concerning the relative contributions as to whether elite performers are 'born and not made' there is common agreement among movement scientists that even if performers have 'natural talent' extensive involvement in practice activities is still essential in order to realise this innate potential (Baker & Davids, 2007). Indeed, retrospective studies examining the developmental histories of expert performers have shown that elite athletes have undertaken significantly more practice than their lesser skilled counterparts, with approximately 10, 000 hours being identified as necessary to reach expert status . Ericsson has built his ‘expert-performance approach’ on the concept of deliberate practice. Deliberate practice has been defined as engagement in relevant activities that require great effort, lots of repetition and opportunities to acquire feedback and is not inherently enjoyable (Ericsson, 2003; Ward, Hodges, Williams, & Starkes, 2004). In his later work, Ericsson (2007) provides a slightly broader definition when he describes practice as deliberate ‘when individuals engage in a practice activity (usually designed by their teachers), with full concentration on improving some aspect of performance’ (p.14). The highly cognitive and mechanistic viewpoint proposed by Ericsson has been interpreted by many practitioners as emphasizing the need for early specialization and the need to practise using highly repetitive drills-the concept of perfect practice. However, given the importance of developing performers with adaptive variability, we would argue that this type of practice is in fact for from perfect and can lead to performance that lacks the flexibility to adapt in the ways demonstrated by highly skilled individuals. Nonlinear pedagogy emphasises the need for practice that adopts the principle of ‘repetition without repetition’ (Bernstein, 1967). In this approach, coaches design representative practice tasks that allow individuals the time and space to explore and discover co-ordination patterns and make decisions that are most appropriate for their unique constraints (Davids, Button et al., 2007). In contrast to the deliberate practice framework, coaching based on a nonlinear pedagogy would not reject unstructured learning environments and would in fact promote informal learning opportunities, including having children design their own games and activities (Kidman, 2005). The importance of designing practice that is not over structured is supported by the counterintuitive findings of Schöllhorn (Under Review: 2007) who demonstrated how adding noise in the form of random movement variability to a target movement can enhance learning for shot putting performance. Schöllhorn used a strategy termed Differential Learning and he required an experimental group to execute between 280-300 shot putt movements with shot weights for males being between 4 and 7.25 kg and females with 3 to 5kg. The training exercises for the differential learning group included left and right hand shot putts: a) Shot with left knee bend, b) shot with stiff right knee, c) shot with high right elbow, d) shot towards the left, e) shot as high as you can, f) shot with left leg without ground contact, g) shot with a straight left arm, h) start fast and continue slow, i) move fast with the lower extremities and slow with the upper limbs. A control group undertook training based on recommendations of the German track and field association developed from international standards. Most intriguingly the performance development of the differential learning group increased in all post-treatment and retention tests significantly. In comparison a traditionally trained group only showed an increase in post-treatment performance. It would appear that creating unavoidable movement variance enhances performance and learning by requiring performers to continuously change movement execution and to scan the high dimensional space of their nonlinear movement system for emergent solutions in a stochastic manner. In this way, the learner is confronted with larger (in comparison to repetitive practice constraints) differences between two consecutive trials that, through the process of Differential Learning, encourages exploration and pick up of information about the stability of the perceptual-motor landscape (Schöllhorn et al., Under Review: 2007). Interestingly, some practitioners have intuitively held similar models of the learning process. For example, Wilf Paish the UK Olympic athletics coach developed a 'throws decathlon' consisting of 10 different types of throws with a shot putt in the 1980s.

In summary, the need for individuals to demonstrate high levels of continued commitment in order to reach elite status would suggest that early practice programmes can involve highly variable activities that do not necessarily have to be in the chosen area of expertise (Côté et al., 2007; Davids, Button et al., 2007). Additionally, providing opportunities to learn by playing modified tasks or games that are inherently enjoyable and intrinsically motivating for the performer will have the dual effect of helping to create 'love' for the sport while at the same time developing the integrated physical, technical, tactical and psychological skills needed for competitive success (Bloom, 1885; Chappell, 2004; Côté et al., 2007; Ericsson, 2007; Jannelle & Hillman, 2003).

11. What do we mean by natural learning (implicit?).

Traditional coaching practice is based on high levels of explicit verbal instruction and augmented feedback (Williams & Hodges, 2005). This approach is described as highly conscious and is based on cognitive views of motor learning as typified by Fitts and Posner's (1967) stages of learning model. Verbal instruction is justified as early efforts by beginners in sport are said to be based on conscious control processes (Masters & Maxwell, 2004). However, recent research has been highly critical of this approach on a number of levels. First, explicit learning appears to lead to skill failure under stress as performers 'reinvest' in conscious, cognitive processing in an attempt to control their co-ordination patterns (Jackson & Farrow 2005; Masters & Maxwell, 2004). Second, research in neuroscience has highlighted that visual information for action is picked up by the dorsal pathway and remains subconscious to the perceiver, while information for object recognition is picked up by the ventral system using conscious awareness (Milner & Goodale, 1995). The final reason why explicit learning may not be the most appropriate strategy for practice in sport is that according to Bernstein (1967) typically movements are not controlled by higher levels of the central nervous system and draw heavily on lower levels of control which regulate movement behaviour subconsciously (Davids, Button et al., 2007). It is no surprise that forcing learners to switch to higher levels of control through providing explicit instructions and feedback will lead to performance disruption and de-automisation (Beek, 2000).

Given the growing wealth of evidence that questions the explicit learning approach, there has been much interest in developing implicit learning methods. A number of techniques, such as incidental and analogy learning have been developed by sport psychologists (see Jackson and Farrow (2005) for a comprehensive list) to try and promote this 'new' approach to learning by 'preventing' conscious rule making by learners during the acquisition process. We would argue that coaches need to go 'back to the future' and promote natural implicit learning by creating environments that typify the exploratory behaviour of young children who learn to crawl, walk and run without recourse to verbal instruction. Approaches such as Teaching Games for Understanding (Bunker & Thorpe, 1982) and Inner Game coaching (Gallwey, 1979) can be used by coaches to provide discovery learning opportunities that mimimise potential disruption to performance by unnatural explicit instruction.

12. Blocked versus Random Practice: An ecological explanation

Although the amount of practice undertaken is clearly delineated with skill development, the quality of practice is also identified as being of equal, if not greater importance (Davids, 2000). A key finding in the practice literature has been termed the contextual interference effect (CI) (see Brady, 1998 for a detailed review). CI research suggests that practising using blocked rather than random practice leads to better performance during the practice phase, but the effect is reversed in retention and transfer tasks with better learning occurring when random practice is adopted. For example, the golfer who practises skills of chipping, driving and putting by simulating playing holes might demonstrate poorer performance during the practice phase than a colleague who practised the three skills in separate 'blocks'. However, the random practice will have resulted in better learning for the real life transfer and retention test which is typified by a competition a few days later. The CI effect has been difficult to prove from a theory perspective. Cognitive accounts suggest explanations based on (1) high levels of processing due to learners forgetting the movement while performing some new task and therefore having to re-construct the movement pattern (T. D. Lee & Magill, 1983) or (2) the random practice condition enabling the learner to have many opportunities to compare and contrast tasks (Shea & Morgan, 1979). Unfortunately, these explanations have had weak support within the literature (T.D. Lee & Simon, 2004). The ecological approach may shed some light on the CI effect. From this perspective, random practice is thought to lead to the learner having to constantly search for appropriate solutions by constantly re-organising the movement system (Davids, Button et al., 2007). This search leads to more unstable coordination patterns initially, but greater adaptability on a longer time scale as the learner acquires a wider and more robust perceptual-motor workspace for the task (Davids et al, 2007). In summary, the ecological perspective highlights the advantages of random practice, although coaches should carefully consider the psychological implications of random practice that can impact on perceived competence (T.D Lee & Wishart, 2005).

Summary

In this paper we have suggested that coaches need to insulate themselves from current fads and fancies by basing their practice on a philosophy that is underpinned by sound theory. We have demonstrated that nonlinear pedagogy, based on key ideas and principles of ecological psychology and dynamical systems theory, provides the coach with such a base enabling the development of programmes that have been predicated on empirical evidence from motor learning studies. Additionally, we have shown that basing practice on motor learning theory need not result in highly structured practice based on reductionist perspective of the learner; rather, skill development should be based on an integrative, inter-disciplinary approach leading to coaching that is more hands-off than traditional coaching models.

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