Applications of Dynamical Systems Theory to Football

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Football is a tactically sophisticated sport requiring understanding of coordination processes within and between players during performance of key dynamic interceptive actions such as passing, shooting and dribbling, heading or catching/punching the ball. Dynamical systems theory is an interdisciplinary framework, utilised to study coordination processes in physical, biological and social systems, which has considerable potential for the study of team ball games, including different codes of football. Recent applications of dynamical systems theory to team ball games have examined coordination processes at two different levels. The first level of analysis concerns coordination of dynamic interceptive actions in performers modelled as movement systems (e.g., Davids, et al., 2000; Davids, et al., 2002). Movement coordination and control in footballers conceived as dynamical movement systems involve two dimensions: (i) coordination between important limb segments to ensure a proximo-distal temporal sequencing in the movements of joint segments of the lower limb when kicking, to facilitate the development of high velocities in the distal segment; and (ii) coordination between a moving ball and an effector is moved to satisfy the spatio-temporal constraints of interception with a controlled amount of force. The second level of analysis has attempted to model the dynamics of interpersonal coordination within patterns of play emerging in typical sub-phases of team ball games such attack and defence and 1 v 1 situations (Grehaigne et al., 1997; McGarry et al., 2002; Araújo et al., 2003). These applications are providing useful insights into processes of motor skill acquisition and tactical development for players and coaches. The aims of this paper are to: (i) present an overview of the theoretical constructs and concepts of dynamical systems theory which are highly relevant for the study of coordination processes at different levels in the context of football; (ii) review some current data emerging from these modelling attempts; and, (iii) draw some implications for coaching behaviours from the main empirical and theoretical developments in a constraints-led approach.

1.1 DYNAMICAL SYSTEMS THEORY AND COORDINATION PROCESSES IN FOOTBALL

Generally, nonlinear dynamical systems are highly inter-connected systems composed of many interacting parts, capable of constantly changing their state of organisation (e.g., weather systems; societies; chemical systems). Complex, dynamical systems in nature have several key characteristics important for the study of coordination processes in football. First, fractal analysis in chaos theory has revealed self-similarity between localised sub-system behaviour and global system behaviour. In applications to football, the characteristic of self-similarity implies that the same underlying principles can be used to explain coordination processes in localised sub-systems (e.g., the emergence of patterns of movement coordination in individual players) and the global system (i.e. the emergence of tactical patterns during sub-phases of football including 1 v 1, 3 v 3 and 11 v 11 situations). Second, dynamical systems can display nonlinearity of behavioural output and have a capacity for stable and unstable patterned relationships to emerge between system parts through inherent processes of self-organisation under constraints (i.e., these systems can spontaneously shift between many relatively stable states of coordination (Davids et al., 2004)).

1.1.1 Constraints on Football Players as Dynamical Movement Systems

Understanding how coordination emerges in dynamical movement systems, with their huge number of micro-components, was defined as the fundamental question in the human movement sciences and has become known as Bernstein's (1967) degrees of freedom problem (e.g., Turvey, 1990). The degrees of freedom of the human body are the many different parts, for example the muscles, joints and limb segments, which are free to vary in position and movement. Bernstein's (1967) seminal definition of movement coordination neatly captured the fundamental problem. The achievement of coordination between parts of the human body was viewed as "the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system" (p.127). Despite the proliferation of degrees of freedom, dynamical movement systems show a surprising amount of order, and it has been known for some time that functional patterns of coordination emerge in individual performers to satisfy competing and cooperating task, informational and environmental constraints (e.g., Newell, 1986). Such classes of constraints interact to pressure the individual movement system into changing its organisational state during dynamic interceptive actions, such as kicking, punching or catching a ball.

Newell's (1986) model of interacting constraints and self-organisation processes has been applied to the study of coordination and control of dynamic interceptive actions in sport (for many examples see Davids et al., 2002; Davids et al., 2004). According to the model, coordination and control emerge under constraints and a relevant question concerns how the motor system degrees of freedom are specifically harnessed during learning of football skills. Bernstein (1967) highlighted the formation of specific functional muscle-joint linkages, later known as coordinative structures, as a method of constraining the large number of degrees of freedom to be regulated in the human movement system. Coordinative structures act as physical constraints, which specify how individual movement system degrees of freedom can become mutually dependent. Anderson and Sidaway (1994) revealed support for these ideas in soccer players. In their study, novices initially showed joint ranges of motion of lower magnitude during kicking practice, compared to more skilled counterparts who exhibited coordinative structures characterised by greater values of flexion and extension in the knee and hip joints. As a result of a 10-week period of exploratory practice, the novices began to approximate the coordinative structures of the skilled footballers by increasing the joint range of motions for the knee and hip during kicking, increasing the amount of knee flexion prior to hip flexion and by extending the knee earlier with a resultant increase in linear foot velocity at ball contact (see Figure 1).

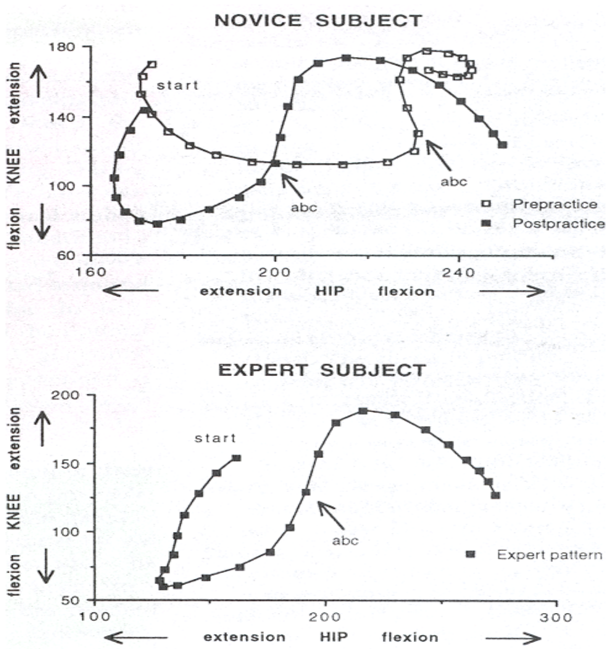

Figure 1 Representative data on coordination of the instep drive towards a target by a novice (top graph) and skilled (bottom graph) performer. Data on pre- and post-practice comparisons are provided for the novice performer. Note the restricted joint ranges of motion in the novice performer prior to practice (open square curve in top graph), the changes in joint ranges of motion after practice for the novice and the increasing similarity with the flexible kicking pattern of the skilled performer, with practice. Data from Anderson & Sidaway (1994). Reprinted with permission from AAHPERD.

These findings supported the dynamical systems interpretation of skill acquisition promoted by Newell (1985), based on Bernstein's (1967) insights. He argued that, early in learning, players typically assemble fairly functional, but rigid, coordination structures to satisfy specific task constraints of football such as passing, dribbling and shooting a ball, whereas later in learning, skilled players practice controlling or varying the parameters of the basic coordinative structure to enhance flexibility of skill performance.

1.1.2 Coordinative Structures and Exploration of Task Constraints

Exploratory practice during discovery learning is valuable at both the coordination and control stage of learning, but for different reasons (Davids et al., 2004). Initially, exploratory practice is useful for football players to assemble functional and unique coordination structures to achieve a specific task goal such as controlling a ball, whereas later in learning exploratory practice allows players to refine and adapt existing basic coordinative structures to enhance flexibility (e.g., control a ball in different ways and under different conditions). In football, exploratory behaviour can be encouraged by manipulating key task constraints to direct the learners' search for effective coordination solutions and an important question concerns the nature of the constraints that learners have to satisfy during motor learning.

One important task constraint that coaches can manipulate is equipment and there have been many claims about the use of smaller and denser footballs, such as the Futebol de Salão (FDS), to enhance the acquisition of ball skills. Araújo et al. (2003) reviewed the evidence surrounding these claims and it appears that there are some benefits to using the FDS to improve ball skills, particularly at the control stage of learning, but not necessarily at the coordination stage. In one study reviewed, Button et al. (1999) examined whether use of the FDS by groups of 11-year-old beginners at soccer would enhance ball control. After a pre-test to equate basic skill level, one group practised dribbling and juggling skills with the FDS, while a control group practised with a regulation size 5 soccer ball. The aim of the juggling test was to keep the ball in the air for as long as possible using any legal body parts under the laws of association football. The aim of the dribbling test was to examine the participant's ability to complete a course of four cones in a zigzag formation as fast as possible whilst keeping the football under control. Results showed that both groups significantly improved juggling and dribbling performance during acquisition. In the juggling test, results indicated that the FDS experimental group juggled the conventional ball more successfully than the control group in the post-test (see Figure 2). Button et al. (1999) suggested that children using a smaller, heavier ball could be guided towards relevant information (such as haptic and proprioceptive sources) for establishing functional coordination structures, enabling effective transfer to other task constraints.

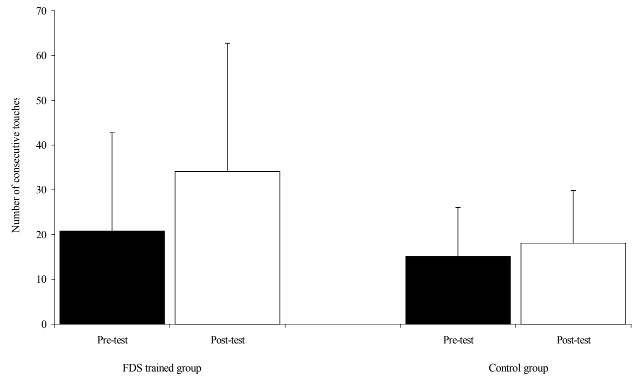

Figure 2 Pre- and Post-Test comparisons on a ball-juggling test for groups of 11-year old children using a FDS and a size 5 soccer ball (control group). Data reprinted from Araújo et al. (2003).

Pre-test data from Button et al. (1999) in Figure 2 suggested that their learners were at the control stage of learning, and there was a need for further work to understand whether beneficial effects of manipulating ball characteristics would also be observed in children at the coordination stage. Chapman et al. (2001) attempted to extend the work of Button and colleagues (1999) by examining whether the task constraints of using the FDS interacted with skill level of learners and by dissociating the effects of ball size and coefficient of restitution on juggling and dribbling skills. To achieve these aims, a sample of completely novice players (at the coordination stage of learning as verified by pre-test scores) aged between 8-11 years old, were investigated, using identical protocols of Button et al. (1999). After the pre-test, all participants were divided into one of three equal, randomly stratified groups. One group practised with the FDS ball, another with the size 3 soccer balls, and a third group of controls was assigned to the size 4 soccer ball. Since the FDS ball approximates the size 3 soccer ball, the comparison of learning to juggle and dribble the FDS, relative to a group practising with a size 4 soccer ball, permitted dissociation of the effects of ball size and ball coefficient of restitution on ball skill acquisition in the children. Means and standard deviations for the dribbling and juggling tests can be seen in Table 1.

Table 1. Means and standard deviations of the juggling and dribbling tests across the time phases. Data reported in Araújo et al. (2003).

Juggling (Touches)				**Dribbling (Seconds)**			
	Pre	Post	Ret		Pre	Post	Ret
FDS	2.48 (± 1.19)	4 (± 1.63)	3.89 (± 2.18)	**FDS**	27.62 (± 3.84)	23.4 (± 2.48)	25.35 (± 3.49)
Size 3	2.66 (± 0.98)	3.85 (± 1.46)	3.42 (± 1.53)	**Size 3**	28.05 (± 6.13)	24.35 (± 3.39)	25.64 (± 3.35)
Size 4	4.38 (± 3.77)	6.33 (± 4.83)	5.33 (± 2.78)	**Size 4**	26.30 (± 3.11)	24.21 (± 2.83)	24.84 (± 2.90)

All three groups significantly improved their juggling and dribbling performance between the pre- and post-tests. The results revealed no significant relative benefits for the acquisition of ball control skills among novice children when practising with the FDS ball, compared to conventional size 3 and 4 soccer balls.

Araújo et al. (2003) pointed out that differences in data on ball control, observed in previous studies of equipment constraints in football, were likely due to the differences in skill level between the groups of children involved in the studies. In the study by Button et al. (1999) the participants were at the control stage (Newell, 1985), having already assembled a basic coordination pattern for juggling and dribbling a ball. In the Chapman et al. (2001) study, the lower pre-test means implied that they were at the co-ordination stage because they had not yet assembled a stable co-ordination pattern for successfully juggling and dribbling a ball. A more precise definition of the learners in the study by Button et al. (1999) may be 'beginners', whereas the children investigated by Chapman et al. (2001) have been aptly described as complete 'novices'. Although there is a need for further research, it appears that manipulating the characteristics of footballs can enhance children's ball control, as long as the learners are already at the control stage of skill acquisition. Stability of equipment constraints seems important to allow exploration of new coordination structures to be assembled, whereas later in learning, exploration of equipment can refine established coordination patterns. Determining how skill level and task constraints mediate the emergence of skilled behaviour poses important challenges for future work in football. Moreover, refined analyses should assess how movement coordination changes with learning in football players.

Given the fractal nature of some dynamical systems, an interesting question concerns whether similar characteristics of self-organisation and emergence under constraints can be found in analyses of the tactical and strategical formations of football teams, conceptualised as dynamical systems. Evidence suggests that the same processes of self-organisation and emergence do exist at the tactical and strategical level of analysis of football.

1.2 FOOTBALL TEAMS AS DYNAMICAL SYSTEMS

Team ball sports in general, and football in particular, can be considered as dynamical systems composed of many interacting parts (e.g., players, ball, referees, court dimensions). Macroscopic patterns of behaviour spontaneously emerge from nonlinear interactions of various components at a more microscopic level of organization, the former being clearly different from the behaviour of each component considered separately (Araújo, et al., 2003; Gréhaigne, 1997; McGarry et al., 2002). In football, the game rhythm is characterized by exchanges of the ball in unequal measure. The game is characterised by an opposed relationship, where each "team must coordinate its actions to recapture, conserve and move the ball so as to bring it within the scoring zone and to score a goal" (Gréhaigne et al., 1997, p.137). The self-organizing dynamical pattern of between-person rhythmic coordination investigated by Schmidt and colleagues not only modelled the equilibrium of coordinative states but also how these coordinative states could spontaneously de-stabilise and change form (Schmidt, et al., 1990; Schmidt et al., 1999). It was proposed that principles of pattern formation underlay between-person dynamics, and the same ideas have been applied to the study of player movements on the football field, since there may be transitions in the state of a competitive game, caused by key events that McGarry et al. (2002) called 'perturbations' (i.e., a key event or aspect of skill that disrupted the "normal" rhythm of the game).

From this viewpoint, the game can be characterized by order-order transitions, where individual actions may destabilize or (re)stabilize the system accordingly. These ideas fit well with tactical considerations in football since, at one level of analysis, the game can be described as a series of sub-phases, such as attacking and defending, and goals within each sub-phase constrain the coordination of movements between attackers and defenders to different extents. Sub-phase work (e.g., 1 v 1; 2 v 2; 3 v 3) is typical of practice organisation in soccer. One important locus of perturbations are 1 v 1sub-phases of football where attackers and defenders are involved in an interpersonal dyad, where the constant adjustment between the positioning of the opposing players is a characteristic of dribbling, and can be understood as a type of interpersonal coordination. Although McGarry et al. (2002) speculated that the quality of an attacker or a defender could be seen in the facility with which he or she disrupts or (re)equilibrates the system, there has been little work examining 1 v 1 sub-phases as processes of maintaining or breaking symmetry in a dynamical system.

1.2.1 Interpersonal dynamics in football

One study of team ball games by Araújo et al. (2002) considered the relative positioning of an attacker with the ball and a marking defender near the scoring area. Attackers and defenders formed closely interacting dyads in which both parties did not typically seek to coordinate actions. In soccer, the aim of dribbling attackers is to 'destroy' the symmetry of this system by "getting rid" of defenders to score, while defenders seek to remain between attackers and the goal in order to stop the attacker from scoring and to recover the ball. When the defender matched the movements of an opponent and remained in position between the attacker and the goal, the form or symmetry of the system remains stable. When an attacker dribbled past an opponent, near the goal, he/she destroyed system stability.

At this level of analysis, therefore, 1 v 1 situations can be described as the creation, maintenance, and dissolution of a dyad, which relies on information about its ongoing coordinative state, that is, its kinematics and its kinetics. According to Araújo et al. (2003). due to the dynamics of competitive games, there is typically not enough information to specify a goal path completely in advance for attackers. Consequently, goal path selection, or decision-making in de-stabilising dyads formed with defenders, can be viewed as an emergent process for attackers.

1.2.2 Emergent decision making in football

Gréhaigne et al. (1997) argued that changes in the momentary configuration of the game have to be examined in the light of the previous configurations, an example of the concept of conditional coupling in dynamical systems theory (Davids et al., 2004). They concluded that: "Choices are made based on position, movement and the speed of one's teammates and opponents. (…) With the opposition relationship, order and disorder can emerge from the play at any moment. In this way, the energy and choices of the players serve to create the conditions for transitions between configurations of play and thus transform the play" (p.148). These transitions may be best understood in terms of the interactions of multiple local factors (place of the players and of the ball, their speed, player's cognitions and morphology, the slippery of the floor, etc.).

This characteristic is known as a process of *soft-assembly*, meaning that the decisions and moves that emerge in 1 v 1 situations are tailored to the immediate performance context, yet they satisfy some general goal. Of particular interest is the intrinsic metric or specific measurement system that attackers use for making decisions such as the critical location on court, relative to the defender's position, at which they need to change direction during their drive towards the goal area. Dynamical systems theory would predict that this decision would not occur at an absolute critical distance every time (e.g., 1.5 m from the defender), but rather would emerge from the intrinsic metric of the specific system formed by each individual attacker and defender. Analysis of the coaching literature (e.g., Bain, et al., 1978) reveals that a candidate control parameter for an attacker-defender dyadic system could be the intrinsic metric of the *interpersonal distance* between the attacker and defender in a 1 v 1 situation. Additionally, the team ball games literature reveals that a potential order parameter could be the median point of the distance of both players to the goal area. In order to test these assumptions, Araújo et al. (2002) investigated whether the equilibrium in attacker-defender dyads is broken when a critical value of interpersonal distance is reached. Obviously, during competition, other factors will constrain the strength of interpersonal coordinative states formed on the court or pitch (e.g., skill level, fitness levels, injuries, relying on non-functional information), but the proposal remains that a basic principle of decision-making in dribbling during team ball games is a symmetry-breaking process, resulting from the interaction of multiple constraints.

To exemplify these arguments we refer to data from studies of the interaction of an attacker and a defender in a 1 v 1 situation in team ball games (exemplified by the task vehicle of basketball), conceptualised as an interpersonal coordinated system, which can result in a stable interactive dyad, since the defender counteracts any movement towards the goal by the attacker (Araújo et al., 2002), as previously described.

In Figure 3a, it can be seen that the attacker-defender-basket system exhibited initial symmetry, which was broken during transition to a new state (in around 4 seconds) at a specific value of the control parameter (i.e. interpersonal distance). A dynamical systems interpretation of this transition process showed that, the attacker-defender system exhibited initial symmetry, which was broken during transition to a new state at a certain value of the control parameter. Analysis of the interpersonal dynamics showed that the attacker was attempting to break the system symmetry by fluctuating direction of the dribble in front of the defender, but the defender was counter-moving in order to maintain the initial steady state. The emergence of the decision on when to drive past the defender was a result of the breaking of symmetry within the dyad. Alternatively, it can be seen in Figure 3b that when the defender has supremacy, the system maintains its symmetry. These findings suggest that dribbling in team ball games can be described as processes of maintaining or breaking system symmetry, as argued by Schmidt et al. (1999) and questions for future research concern acquisition of skill in emergent decision-making, the nature of control parameters, the bodyscaling of dribbling actions by attackers, and the influence of previous plans for action.

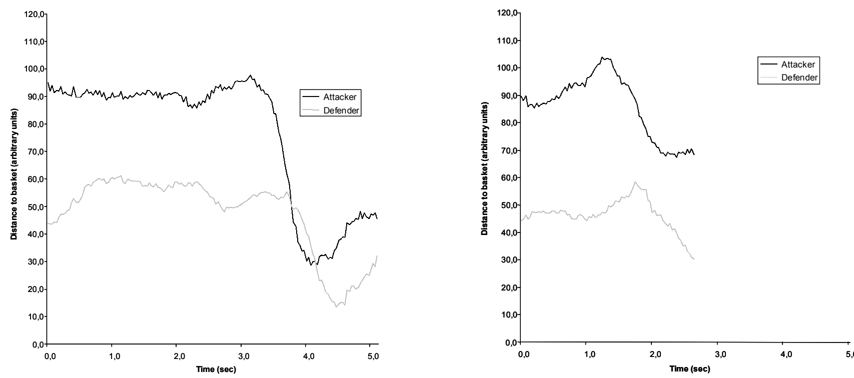

Figure 3 Distinction between individual attacker and defender's distance to basket: a) Right graph showing a slight attacker's advantage; b) Left graph showing defender's supremacy. Data reprinted from Araújo et al., 2003.

1.3 A CONSTRAINTS-LED PERSPECTIVE IN FOOTBALL: IMPLICATIONS FOR COACHES

What are the implications of a dynamical systems approach to understanding learning and performance of football skills and tactics? First, there is a clear emphasis on discovery learning. Exploratory practice encompasses problem solving behaviours and is commonly referred to as active learning, because players participate actively in the learning process rather than passively receiving knowledge. Players are encouraged to explore and assemble their own tentative solutions to motor problems during exploratory practice. Experience of 'discovering' various solutions to the task, whether successful or not, is essential in learning to explore and exploit movement and sub-phase system dynamics (Davids, et al., 2004). Discovery learning occurs in a practice context similar to the performance context enabling the player to become more attuned to the available information sources. Discovery learning promotes variability in practice and exploration of movement dynamics, enhancing the search process by increasing learner's exposure to varieties of task solutions (Newell & McDonald, 1991). There are also other important benefits for the learner. While a player actively participates in learning, they are able to concentrate on exploring potentially important sources of information as opposed to independently satisfying task demands prescribed by the coach. This active involvement in practice provides a foundation whereby coordinative structures can be assembled in the early stages of learning so that later in practice they can be strengthened and optimised for skilful performance. Appropriately constrained learning environments provide the player with the opportunity to receive relevant intrinsic feedback necessary for refining movement responses to perceptual and other information constraints.

An important issue with augmented informational constraints is that, in practice, instructions and feedback from the coach are often provided in a way that induces an internal focus of attention within the player. Focus of attention in motor learning relates to the learner's attention to either limb and body movements (an internal-focus on movement dynamics) or on the effects of a motor pattern on the environment (an external focus) such as the ball's trajectory in flight after being kicked (e.g., Wulf et al., 1999; Shea & Wulf, 1999; Wulf et al., 2002). With respect to football, Wulf et al., (2002), examined the effects of an internal/external focus and frequency of feedback on the learning of a lofted pass in football. Statements were provided to reinforce the attention of the learners to either an internal or external focus. Internal-focus feedback comprised such statements as 'Position your foot below the ball's midline to lift the ball' and 'Position your body weight and the non-kicking foot behind the ball' and external-focus feedback comprised statements such as 'Strike the ball below it's midline to lift it; that is, kick underneath it' and 'To strike the ball, create a pendulum-like motion with as long a duration as possible'.

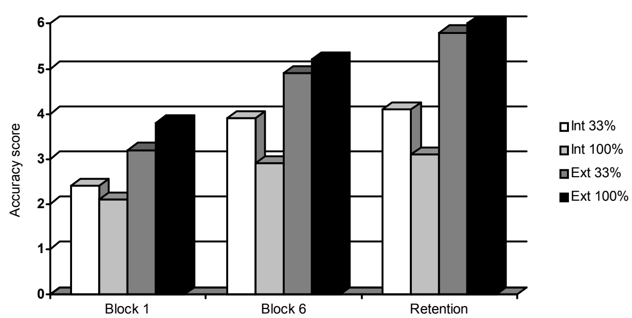

Figure 3. Graph adapted from Wulf et al., 2002. Accuracy scores of the Int - 33, Int - 100, Ext – 33 and Ext - 100 groups.

As the results show in Figure 3, there was clear evidence of an immediate effect on performance outcome and learning experienced by both external-focus feedback groups. Generally, providing information about a function solution (goal-relevant information) accelerates learning more efficiently than providing information about "correct" means to achieve a solution (i.e., on one of the possible pathways to achieve a functional solution). Furthermore, the interaction between feedback frequency and attentional focus resulted in more effective performance during both practice and retention in the group receiving reduced (33% of trials) external-focus feedback relative to the constant (100% of trials) external-focus feedback group. These data indicated that receiving external focus feedback once in every three trials is as functional for learning as receiving external focus feedback on every trial. These findings highlight the detrimental effects that an internal focus on body parts and movement dynamics has on learning and performance in a dynamic sport such as football. Furthermore, these findings support the idea that discovery learning affords the player more opportunity to explore other potentially important external sources of information using an external focus of attention as opposed to providing the player with an internal focus of attention.

Instructions that direct a player's attention to an internal focus might deprive him/her of the opportunity to discover and satisfy the multiple task constraints unique to each individual. Instructions relating to task goals early in practice should attempt to direct the search toward relevant feedback sources that take into account their movement effects on the environment. A less prescriptive and more self-regulated feedback mechanism, which complements discovery learning and encourages the player to explore the task environment, seems to be a more appropriate instructional technique.

A constraints-led approach to coaching creates an environment that facilitates discovery by guiding a player through a range of potential movement solutions in the search for an optimal movement response. Individual responses are unique to each player, and results in effective retention and transfer of movement skills that require a less prescriptive 'hands-off' approach to coaching (Handford et al., 1997). This can be achieved through the manipulation of key constraints on the player leading to a change in the interaction between constraints, which in turn leads to changes in movement behaviour. It is argued that a thorough grounding of the principles of task constraints forms the basis for a constraints-led approach to practice in sport (Davids, et al., 2004). The constraints-led approach is learner-centered, individual specific and involves a minimum of coach-player interaction, in sharp contrast to more traditional, didactic methods that emphasise verbal instructions, technique and task decomposition, generalising learning strategies across groups of individuals.

The primary task of the coach is to identify the key task, environmental and organismic constraints acting on the player and to understand how each one can *bias* the self-organization of the outcome movement. The ability of the coach to manipulate key constraints in a imaginative but functional way is seen as a fundamental principle toward creating an effective learning environment and one that is central to further task development. The process involves skill progression through task development rather than skill reductionism through task decomposition. Task solutions emerge from the time when the player first perceives relevant information for action to a point after which information about action (movement effect feedback) has been received. With the linking of information for action and action for information between player and environment, perception-action couplings emerge with practice and form the principal basis for structuring progressive task development practices. Variability in discovery learning is encouraged in players within the limits imposed by system constraints and consideration should be given to the function and purpose of intra- and inter-individual variability when manipulating constraints for group practices and games (e.g., Teaching games for understanding TGFU and conditioning games). Recent developments in thinking games for understanding have been brought about by a perceived need for less technique-based coaching and an increased emphasis on game-related skills, which are individually specific and encourage maximum participation. Coaches are challenged to adopt creative ideas, even borrowing from other sports, to manipulate the interaction of constraints on players, leading to challenging and exciting learning environments.

Progressive task development is achieved by altering the balance of interacting constraints on movement behaviour by manipulating one or several of the specific task constraints but also environmental and individual constraints too. Having identified the key individual constraints on the player, the coach designs a succession of progressive changes to task constraints and may even consider implementing environmental and individual constraints to facilitate and guide the learning process. For example, during dribbling variability of movements is to be encouraged as attackers explore ways to break the symmetry of dyads. Task constraints available for manipulation include changing the task goal over time and making subtle regulatory modifications to elicit desired changes in behaviour and appropriate decision making. Altering the practice rules that apply to attack and defence will initiate many of these changes for the coach, including constraints on types and number of passes, tackles and contacts on ball, number of players involved, sub units of the team, units and teams each with differing task goals, duration and time allowed in/out of a zone, channel or game, player roles and positions, the number, dimension and strategic positioning of goals and also boundaries and markings which can provide implicit rules for modified and conditioning games.

The exploratory activities of the players can be made against defenders with different body dimensions such as lower limb lengths; or against defenders with different displacement velocities, or with different laterality preferences, or at different distances and spatial positions in relation to the goal area. It is possible to focus more on perception (i.e, in detecting action possibilities), or on actions (i.e., in the execution of action possibilities), but keeping the link present. A third possibility is to provide the formation of new links between perception and action (i.e. creating new action possibilities) (Araújo et al., 2003). These different focus means that, practice must be holistic (i.e., maintaining perception-action coupling) but must set different priorities (i.e., goals) according to player's skills. In sum, coaches should provide tasks where players learn how to soft-assemble adaptive behaviours in ways that respond to local context and exploit intrinsic dynamics.

1.4 CONCLUSIONS

The theoretical analysis of skill acquisition in sport as an emergent process under constraint is in its infancy, but it is becoming clear that concepts such as body-scaling of actions and symmetry-breaking during dribbling in order to seek phase transitions are potentially useful ideas that need to be fully investigated during practice and in future research programmes. In particular, manipulation of important variables such as practice structure and organisation and the nature of equipment used during learning will be key to understanding the emergence of skilled behaviour. It is clear that the role of the coach from a constraints-led viewpoint is likely to differ in subtle ways from traditional conceptualisations. For example, in the important task of providing feedback to athletes, a focus on functional solutions (i.e. the goal to be achieved) provides better opportunities to constrain learners' search for emergent task solutions during discovery learning. It appears that an external focus of attention may not interfere with self-organisation processes of the movement dynamics as athletes explore the tasks. These, and many other issues, could form the basis of a theoretico-practical programme of work on a constraints-led approach to skill acquisition in different codes of football for many years to come.

1.5 REFERENCES

Anderson, D.I. & Sidaway, B. (1994). Coordination changes associated with practice of a soccer kick. *Research Quarterly for Exercise and Sport,* **65**, 93-100.

Araújo, D., Davids, K., Sainhas, J. & Fernandes, O. (2002). Emergent decision-making in sport: a constraints-led approach*. Communication to the International Congress on Movement, Attention and Perception*, Poitiers, France.

Araújo, D., Davids, K., Bennett, S.J., Button, C. & Chapman, G. (2003). Emergence of sport skills under constraints. *In Skill Acquisition in Sport: Research, Theory and Practice,* (Edited by A.M. Williams and N.J. Hodges). London: Routledge, Taylor & Francis.

Bain, B., Hayes, D., & Quance, A. (1978). *Coaching Certification Manual - Level two.* Canada: J. Seaman, Basketball Canada.

Bernstein, N.A. (1967). The Control and Regulation of Movements. London: Pergamon Press.

Button, C., Bennett, S., Davids, K. & Stephenson, J. (1999). The effects of practicing with a small, heavy soccer ball on the development of soccer related skills. *Invited Communication to British Association of Sports and Exercise Sciences Annual Conference*, Leeds Metropolitan University, UK.

Chapman, G., Bennett, S.J. & Davids, K. (2001). The effects of equipment constraints on the acquisition of juggling and dribbling in soccer. *Communication to 6th Annual Congress of European College of Sports Science (Perspectives and Profiles),* Cologne, Germany.

Davids, K., Lees, A. & Burwitz, L. (2000). Understanding and measuring coordination and control in soccer skills: Implications for talent identification and skill acquisition. *Journal of Sports Sciences,* **18**, 703-714.

Davids, K., Button, C., & Bennett, S.J. (2004). Coordination and Control of Movement in Sport: An Ecological Approach. Champaign, Ill: Human Kinetics.

Davids, K., Savelsbergh, G. J. P., Bennett, S. J. & Van der Kamp, J. (2002). Interceptive Actions in Sport: Information and Movement. London: Routledge, Taylor & Francis.

Gréhaigne, J.F., Bouthier, D., & David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences*, **15**, 137-149.

Handford, C., Davids, K., Bennett, S. & Button, C. (1997). Skill acquisition in sport: Some applications of an evolving practice ecology. *Journal of Sports Sciences* **15**, 621-640.

McGarry, T., Anderson, D., Wallace, S., Hughes, M., & Franks, I. (2002). Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences*, **20**, 171-181.

Newell, K.M. (1985). Co-ordination, Control and Skill. In, *Differing perspectives in motor learning, memory and control* (edited by D. Goodman, R.B. Wilberg, and I.M. Franks), pp. 295-317. Elsevier Science Publishers: North Holland.

Newell, K. M. (1986). Constraints on the Development of Coordination. In M. Wade, & H.T.A.Whiting (Ed.), *Motor Development in Children: Aspects of Coordination and Control* (pp. 341-360). Dordrecht, Netherlands: Martinus Nijhoff.

Newell, K. M., & McDonald, P.V. (1991). Practice: A search for task solutions. In R. Christina & H.M. Eckert (Eds.), *American Academy of Physical Education papers: Enhancing human performance in sport: New concepts and developments* (pp. 51-60). Champaign, IL: Human Kinetics.

Schmidt, R. C., Carello, C., & Turvey, M.T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, **16**, 227-247.

Schmidt, R. C., O'Brien, B. & Sysko, R. (1999). Self-organization of between-persons cooperative tasks and possible applications to sport. *International Journal of Sport Psychology*, **30**, 558-579.

Shea, C.H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Science.* **18**(4), 553-571.

Turvey, M.T. (1990). Coordination. *American Psychologist.* **45**, 938-953.

Wulf, G., Lauterbach, B., Toole, T. (1999). The learning advantages of an external focus of attention in golf. *Research Quarterly for Exercise and Sport*. **70**(2), 120-126.

Wulf, G., McConnel, N., Gartner, M., & Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. *Journal of Motor Behaviour*. **34**(2), 171-182.