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Athletes and sports teams as complex adaptive system: A review of implications for learning design

Atletas y equipos deportivos como sistemas adaptativos complejos: Una revision de las Implicaciones para el diseño del aprendizaje

Keith Davids
Centre for Sports Engineering Research, Sheffield Hallam University, UK

Abstract

Ecological dynamics is a systems-oriented theoretical framework which conceptualizes sport performers as complex adaptive systems. It seeks to understand the adaptive relations that emerge during coordination of interactions between each performer and a specific performance environment. This approach has identified the individual-environment relationship as the relevant scale of analysis for explaining how processes of perception, cognition and action underpin expert performance in sport. This theoretical overview elucidates key ideas from previous work identifying functional characteristics of complex adaptive systems, such as co-adaptation, emergent coordination tendencies and capacity to utilise affordances, which underlie performance and learning in team and individual sports. The review of research focuses on how key principles of ecological dynamics inform our understanding of learning and transfer, and their impact on practice task design in sport development programmes. To support this analysis, data from research on performance of elite and developmental athletes in individual and team sports are presented to highlight important principles of learning design from an ecological dynamics perspective.

Key words: Ecological dynamics; complex adaptive systems; coordination tendencies; emergence; constraints; affordances; transfer; learning design.

Resumen

La dinámica ecológica es un marco teórico orientado a los sistemas que considera a los atletas como sistemas complejos adaptativos. Busca comprender las relaciones adaptativas que emergen durante la coordinación de las interacciones entre el deportista y su medio de actuación específico. Este enfoque ha identificado la relación individuo-ambiente como la escala relevante de análisis para explicar cómo los procesos de percepción, cognición y acción subyacen al rendimiento experto en el deporte. Esta revisión teórica dilucida las características funcionales esenciales de los sistemas adaptativos complejos, tales como la co-adaptación, las tendencias emergentes de coordinación y la capacidad de utilizar las *affordances*, que subyacen al rendimiento y al aprendizaje en los deportes individuales y colectivos. La revisión se centra en cómo los principios fundamentales de la dinámica ecológica informan nuestra comprensión del aprendizaje y la transferencia, y su impacto en el diseño de tareas prácticas en los programas de desarrollo deportivo. Para apoyar este análisis, se presentan datos de investigación sobre el rendimiento de atletas en proceso de desarrollo y de alto nivel en deportes individuales y de equipo, para destacar importantes principios de diseño de aprendizaje desde una perspectiva dinámico-ecológica.

Palabras clave: dinámica ecológica; sistemas complejos adaptativos; tendencias de coordinación; emergencia; limitaciones; *affordances*; transferencias; diseño de aprendizaje.

Correspondence/correspondencia: Keith Davids
Sheffield Hallam University | Centre for Sports Engineering Research
Faculty of Health and Wellbeing |A217, Collegiate Hall, Collegiate Crescent, Sheffield S10 2BP, UK
Email: k.davids@shu.ac.uk

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A fundamental challenge for sport scientists, skill acquisition specialists and pedagogues is to develop theoretical principles of performance and learning to enhance the acquisition of skill and expertise in sports. A principled theoretical framework is needed to capture the nature of the learning process and of the learner (Davids, 2012). This article overviews how individual athletes and sports teams can be conceptually modelled as complex adaptive systems, providing a comprehensive theoretical rationale for understanding implications for learning design. Complexity in neurobiology is ubiquitous and the traditional reductionist philosophy of attempting to isolate system components for scientific analysis cannot reveal necessary insights on the behaviours of complex adaptive systems (Riley et al., 2012). Complex adaptive systems have been technically defined as neurobiological organisations with two or more interacting system components (Handford et al., 1997).

Athletes and Sports Teams as Complex Adaptive Systems

A major theoretical influence on ecological dynamics is dynamical systems theory, a multidisciplinary perspective which explains how complex adaptive systems change the state of organization between system components over time by exploiting inherent system *self-organisation tendencies*. This process is exemplified in sport by the changes in coordination of individual athletes as they transit between different movement patterns when running, swimming or cycling, or the interpersonal interactions of competing and cooperating players in sports teams (see Passos & Davids, this issue). The relations between system components in athletes and sports teams can be continually re-organised to achieve task goals, particularly as performance constraints change (Davids, 2012). Dynamical systems theory is useful to understand the dynamics of the emergent coordination tendencies in system states (Kelso, 1995; 2012). Spontaneous transitions (small or large) in the (re)organization of the degrees of freedom of complex adaptive systems have been modelled and explained using tools and concepts of mathematics and physics. In dynamical systems theory, the behaviours of continuously changing, evolving, developing and adapting systems can be explained, at multiple scales of analysis, with the same underlying abstract principles, regardless of a system's structure and composition (Kelso, 1995). These ideas are instrumental in capturing how the component interactions within an individual performer or between members of a sports team, and a specific performance environment, can be formally modeled, theoretically conceptualised and empirically studied as complex adaptive systems (Davids, et al., 2014). Riley et al. (2012) argued that interpersonal and intrapersonal coordination tendencies observed in such systems are predicated on the formation of synergies between system components, all temporarily assembled to achieve specific task goals. In particular they noted that "Interpersonal coordination of bodies and minds exhibits the same hallmarks of synergies and context sensitivity as intrapersonal coordination" (p25).

Within-individual interactions (movement coordination) display the same hallmark properties of *synergy formation under constraint* and *sensitivity to surrounding information* as those observed in between-individual relations (interpersonal interactions between teammates and with opponents) (Riley et al., 2012). In both performance contexts a key strategy is to identify the nature of the information that constrains system dynamics over different timescales. Complex adaptive systems in sport are open systems whose components can be continuously regulated through the influence of surrounding informational constraints on self-organisation processes (Handford et al., 1997). Such systems have many degrees of freedom which need to be continually re-organised in the service of functional goal-oriented behaviours (Bernstein, 1967). These insights suggest that successful performance in sport, of individuals and teams, involve the continuous (re)organization of system components, regulated by surrounding information sources, to achieve performance outcomes.

Components of complex adaptive systems include the degrees of freedom in athletes (e.g., muscles, joints, limbs in an individual performer) and sports teams (coordination between teammates and interactions with defenders) (Passos et al., 2013; Passos & Davids, this issue). Performance in team and individual sports is sustained by the emergence of temporarily assembled synergies or coordination tendencies from relevant system degrees of freedom (coordination patterns in skilled athletes and coordinated interactions between attackers and defenders in team sports) (Handford, et al., 1997; Passos et al., 2013).

Co-adaptation in complex adaptive systems

The emergent interactions between components of complex adaptive systems under constraints have been studied for some time. An important theoretical mechanism for explaining how coordination tendencies emerges between parts of a complex adaptive system relies heavily on the concept of *co-adaptive moves* in evolutionary systems (see Kauffman, 1993; Bak & Chialvo, 2001). For example, in the study of complex evolutionary systems, Kauffmann (1993) noted how transitions in organisation were most prevalent when co-evolving agents re-organised system components to modify system dynamics in order to adapt to environmental changes. Kauffman's (1993) modeling of evolutionary processes from the perspective of spontaneous self-organizing system dynamics provides a valuable theoretical framework for sport scientists seeking to understand the acquisition of skill and expertise in individual and team sports. In complex adaptive systems, varied patterns of behavior can emerge as individual players co-adapt their actions to each other or to significant objects, events and features of a performance environment in order to achieve specific outcomes or goals (e.g. punch a heavy bag in boxing; use an ice pick to secure an anchor point on an ice fall; to score a try in rugby union; to press an opponent in basketball). In individual and team sports, these dynamically co-adapted interactions between system components can be characterised as intra- and inter-personal coordination tendencies, respectively. These system interactions can spontaneously emerge when previously uncorrelated components (neurons, muscles, joints in an individual performer or teammates in a team sport) suddenly become interrelated and entrained under ecological constraints of performance environments (Kauffmann, 1993; Juarrero, 1999; Guerin & Kunkle, 2004).

Co-adaptive moves of athletes can emerge in anticipation of, and response to, changes in informational constraints over the course of a performance (such as sudden changes in wind or light amplitudes during climbing. The capacity for emergent co-adaptation can provide performers with advantages in overcoming inherent system latencies, exploiting intentions, improving accuracy and reliability, exploiting sources of information uncovered through exploratory activity and coping with environmental and task dynamics (Davids, 2012). Sophisticated patterns in the dynamics of complex adaptive systems are formed as individual components continuously co-adapt to each other's behaviours (e.g., cooperating or competing players in team sports) or components (e.g., self-organising muscles and joints of an athlete's body). Through the process of co-adaptation in neurobiological systems, functional performance behaviors can emerge out of interactions between interdependent constituents of the system (Kauffmann, 1993).

The property of co-adaptation has been observed in numerous studies of *neurobiological system* performance in individual sports. For example, it was demonstrated in a study by Hristovski, Davids, Araújo and Button (2006) who investigated the impact of manipulating target distance on boxing action patterns of novice boxers. Distance between boxers and a punching bag was varied during practice task constraints when participants were asked to strike a heavy bag with actions that emerged. They were not provided with specific instructions on which actions to use in the task and it was found that different scaled-body distances to target afforded the emergence of different boxing patterns (e.g., hooks, jabs, uppercuts). Interestingly, at a critical scaled-body distance (0.6), boxers entered a co-adaptive state which allowed them to flexibly switch between any of the boxing action modes that they had previously learned. It seemed that the scaled-body distance value of 0.6 was critical in pushing the boxer-target system to a region of dynamic stability (technically known as metastability (see Kelso, 2012)), from where many different coordination tendencies could be spontaneously activated under the task and the perceived environmental constraints (Hristovski et al., 2006). At other values of scaled distance this level of flexibility in emergent actions was not observed.

In *collective neurobiological systems*, such as sports teams, the individual performer has been conceptualized as the base unit degree of freedom (Passos et al., 2013). Team sports represent highly dynamic performance environments because of the continuous changes in the location, positioning and movements of competing and cooperating players (Passos & Davids, this issue). Due to the highly interactive nature of the performance environment in team sports, emergent opportunities for action are constrained in time and space. It has been observed that individual organisms use relatively simple local behavioural rules to create rich structures and patterns at a collective system level that are much more complex than the behaviour of an individual in the system. In the 'complexity from simplicity' model of understanding behaviours of complex adaptive system, research has shown how these local rules can lead to the emergence of sophisticated states of organisation in a global system (Riley et al., 2012). For example, in team games, sophisticated attacking and defending patterns of play emerge from continuous attacker-defender interactions (for some examples, see Passos & Davids, 2015). The constraints of a competitive environment in team sports require that performers continuously co-adapt to the behaviours of teammates and opponents in close proximity on the field of play. Variables like relative angles between competing individuals, values of interpersonal distances between an attacker and defender, relative velocity of two moving competitors, and team centroids (a variable showing the location of a team's performance centre of gravity) have been empirically verified as relevant variables for understanding interpersonal coordination tendencies of team sports players as agents in a complex adaptive system (see Passos & Davids, 2015).

This perspective identifies attackers and defenders as components of a self-organising system that are linked by visual (and other) informational fields. The process of co-adaptation between individuals in team games can lead to the emergence of a spontaneous pattern forming dynamics. Processes of co-adaptation in team sport performance have been observed during the informationally-constrained interactive dynamics created in the changing relative positioning between an attacker and defender competing as a dyadic systems in several different team sports including rugby union, futsal, basketball and football (for examples from previous research see Passos & Davids, this issue). For example, previous research in the team sport of rugby union investigated the relative positioning and relative velocity of an attacker-defender dyad near the try line (Passos et al., 2013). Research recorded interactions of attacker-defender dyads, specifically the first derivative of the collective variable (relative velocity between an attacker and defender) over time during the interactions. When there were no differences observed between the players' relative positioning, the first derivative (relative velicty) values tended towards a value of zero. When an attacker achieved a higher relative velocity of movement than a defender, the first derivative values tended to increase with distance from the minimum (i.e. zero). On the other hand, when a defender's relative velocity is higher than an attacker's, the first derivative values tended towards the minimum. It was hypothesized that the divergence of running line speed (i.e. players' relative velocity) between an attacker and defender in the region before the zero crossing point (the point in a dyadic system interaction when a clean try or a tackle emerges, where an attacker passes a defender), is a key constraint on the stability of the dyad (i.e. a critical period), moving the system to one of the attractor states previously identified.

An increase in the magnitude of fluctuations in the first derivative of relative velocity may be interpreted to suggest that the system was approaching a region of self-organized criticality, which means the system is poised for a transition. A sudden decrease in first derivative values meant that the players were changing their relative positions very quickly, which is associated with the emergence of a clean try. Every time the first derivative values got closer to 0 m/s, this value signalled that the players were able to maintain their relative positioning towards each other. This situation it is usually consistent with successful tackles where defenders are able to counterbalance an attacker's decisions and actions. The lowest value achieved is the inflection point, signifying the moment when an attacker passed a defender. Close to 0º (zero degrees) the defender maintained system stability by successfully counterbalancing the attackers' decision and actions, an example of co-adaptive moves in the interpersonal dynamics of the dyad. Alternatively, when values were far from 0º, players had altered their relative positions. In these situations the attacker had the ability to increase locomotion velocity to create the fluctuations needed to de-stabilize the system, allowing him to pass the defender.

In ecological dynamics, interpersonal interactions between competing and cooperating athletes provide influential information sources within a performance setting which constrain the emergent coordination tendencies between an individual and a performance environment (Newell, 1986; Handford et al., 1997).

From this perspective, practice task constraints can be designed to *simulate* the constraints of competitive performance environments, providing opportunities for team games players to explore relations with key informational constraints of a performance environment. An important issue concerns how such simulations can enhance transfer of skills acquired during practice to competitive performance environments in both team and individual sports. As noted previously, skill acquisition is the creation of a functional relationship between each individual athlete and a performance environment (Araújo & Davids, 2011). The next section addresses the theoretical principles of ecological dynamics that are relevant to learning and transfer, clarifying how similar properties of neurobiological systems and collective systems underpin representative learning design of practice environments in individual and team sports.

Learning Design in Ecological Dynamics

A most influential aspect of ecological dynamics concerns the relevant scale of analysis for understanding human behaviours like learning and performance: the *person-environment relationship* (Warren, 2006; Araújo & Davids, 2011; Davids et al., 2014; for a recent acknowledgment of this idea see also Zelaznik, 2014). From this perspective, the acquisition of expertise in individual and team-based sports is predicated on emergence of information-based interactions between each athlete and a specific performance environment (Davids et al., 2014). This is a fundamental principle of learning design in individual and team sports. Perceptual variables in a performance environment are continuously perceived by each athlete when coordinating interactions with events, objects, surfaces, terrain dimensions and features, and other athletes to regulate performance-related behaviours. This athlete-environment interactive process leads to the coupling of key information sources to goal-directed movements as each individual adapts to changes in a performance context. *Information-movement couplings* are coordination tendencies that emerge during continuous interactions of sport performers with key objects (objects to avoid, strike or catch in ball games), surfaces (properties of a rock surface to climb or scramble over or an icy lake to skate across), events (the sudden acceleration of a lead athlete in a triathlon race or a change in tactical patterns of an attacking team), terrain dimensions (field width and length) and features (markings and target areas on field) and significant others (changes in positioning and movements of teammates and opponents changes). The continuous, adaptive interactive process of sport performance signifies that an individual athlete, sub-group (defensive line) or team cannot become completely *dependent* on the information available in a performance environment to regulate their intentional behaviours through the use of instantaneous feedback loops. This control strategy would be too reactive in nature. Nor can athletes perform completely *independently* of their surrounding environment (through a putative shared mental model of performance or by strictly adhering to prior coaching instructions) (Seifert et al., 2013). Indeed, the actions of an individual athlete or sports team need to combine intentions, perception and action in an *emergent* manner to take advantage of the dynamical nature of the information present in performance/learning environments so that performance behaviours can be functionally regulated.

The idea of emergent coordination tendencies has received widespread support in previous research studies on performance in individual sports (e.g., during elite coaches' analyses of run-ups in cricket bowling and long jumping (Greenwood et al., 2014), in elite springboard diving performance (Barris et al., 2014), and in skilled ice climbers (Seifert et al., 2013). As they emerge, coordination tendencies are underpinned by each individual's structural and functional characteristics relative to informational constraints in a specific performance environment (e.g., the liquid properties of an aquatic environment (Seifert et al., 2014) or the conditions of a sailing regatta (Araújo et al., 2014) or the dimensions of a football field (Silva et al, 2014). Gibson's (1979) ideas on information provide a basis for designing task constraints of practice programmes in sport, so that relationships between key sources of information and actions can be harnessed and maintained by developing experts. The data from existing research studies in ecological dynamics suggest that informational variables emerging during ongoing interpersonal interactions of athletes (e.g., angular relations, relative velocities, and interpersonal distances) provide *affordances* (invitations for action) which can be utilised by players and explored during practice.

Affordances in sport

According to Gibson's 1979) insights, different perceptual variables provide *affordances* for athletes because they invite different opportunities for actions in individual and team sports. In sport, affordances are relations between an athlete and a performance environment which may be directly perceived, inviting adaptive actions from individuals under different performance condition (Gibson, 1966, 1979; Jacobs & Michaels, 2007; Withagen, et al., 2012). In ecological dynamics, information is perceived as opportunities to act and emerges from the continuous interactions of an athlete with key features of a performance environment studied at the ecological scale of analysis (Araújo et al., 2006; Fajen et al., 2009; Gibson, 1979). Perceiving an affordance is to perceive how one can act when faced with specific conditions in a performance environment. Withagen et al. (2012) proposed that affordances are action possibilities that invite behaviours from individuals, which are individual-specific and time-based, dependent on past experience, learning and development for their utilization. Affordances, therefore, have an objective (they exist in a performance environment) and subjective (they need an actor to perceive them) dimension. They suggested that the specific motivations and intentions of each individual athlete emerge during performance as information-movement couplings or synergies compete for affordances in a performance environment.

These ideas emphasise the role of affordances in design of habitats and environment, prompting the notion that pedagogues should be conceived as 'learning designers' (for a comprehensive rationale of this idea see Davids, 2012). A key task for pedagogues from this ecological dynamics rationale of learning design in individual and team sports is to understand how to design multiple different affordances into practice task simulations of a competitive performance environment. This approach to sport pedagogy reveals how principles of transfer can underpin learning design in team and individual sports. Designing multiple affordances into a practice environment can support their exploration and discovery by individuals differing in skills, experience and action capabilities. From this viewpoint, skill acquisition in team and individual sports is a cyclical process, predicated on the ability to detect relevant sources of information that offer individuals an opportunity to act, resulting in further actions which reveal further affordances in a continuous way (Fajen et al., 2009).

This understanding of learning design captures the intertwined relations between intentions, perception and action during sport performance. The implication is that the multiple affordances existing in a performance environment need to be identified by coaches and teachers and designed into learning environments which simulate ecological constraints of competitive conditions. Previous research in individual and team sports on behavioural transfer between learning and performance contexts has investigated how affordances support interpersonal interactions of athletes and performance environments to understand effects on performance outcomes (see Pinder et al., 2011, Travassos et al., 2012).

For example, Pinder and colleagues (2011) analysed performance of individuals on a cricket batting task, revealing how distinct task constraints led to the emergence of adapted, functional coordination solutions. Skilled young cricketers were asked to bat under different conditions of ball projection and provided with no specific instructions on how to perform. Against a ball projection machine, advanced information sources from a bowler's actions were removed, causing significant adaptations in movement initiation time. The task constraints also resulted in reduced peak bat swing velocities and poorer quality of bat–ball contact, compared to when participants batted against an actual bowler. Pinder et al. (2011) also found that, when batting against a two-dimensional video image of a bowler, batters were able to use information from the bowlers' action, enabling fidelity of initial behavioral responses consistent with the task of batting against a "live" bowler. However, against the video image, without the requirements of actually intercepting a ball and without ball flight information, significant variations in downswing initiation timing and peak bat velocities were observed. In another study (of one-handed catching), Panchuk et al. (2013) observed similar variations in emergent coordination tendencies when informational constraints were changed. The kinematics of hand movements and gaze behaviours of participants were recorded as they attempted to catch balls projected from a ball machine that was synchronised with video images of a thrower throwing a ball and its trajectory. Data showed that participants' catching performance was less successful when advanced perceptual information from the video images of the throwing action was not available to constrain coordination of hand movements and gaze behaviours. When perceptual information from the throwing action was unavailable, less functional performance behaviours emerged from participants, such as tracking the ball later in flight. They also followed less of its flight path, initiated their interceptive movements later and moving the hand faster. The findings revealed that successful performance of dynamic interceptive actions required integration of advanced visual information from kinematic information from a throwing action and from a thrown ball's trajectory in flight.

A major theoretical influence on ecological dynamics is dynamical systems theory, a multidisciplinary perspective which explains how complex adaptive systems change the state of organization between system components over time by exploiting inherent system *self-organisation tendencies*. This process is exemplified in sport by the changes in coordination of individual athletes as they transit between different coordination patterns when running, swimming or cycling, or the interpersonal interactions of competing and cooperating players in sports teams (see Passos & Davids, this issue). The relations between system components in athletes and sports teams can be continually re-organised to achieve task goals, particularly as performance constraints change (Davids, 2012). Dynamical systems theory is useful to understand the dynamics of the emergent coordination tendencies in system states (Kelso, 1995; 2012). Spontaneous transitions (small or large) in the (re)organization of the degrees of freedom of complex adaptive systems have been modelled and explained using tools and concepts of mathematics and physics. In dynamical systems theory, the behaviours of continuously changing, evolving, developing and adapting systems can be explained, at multiple scales of analysis, with the same underlying abstract principles, regardless of a system's structure and composition (Kelso, 1995). These ideas are instrumental in capturing how the component interactions within an individual performer or between members of a sports team, and a specific performance environment, can be formally modeled, theoretically conceptualised and empirically studied as complex adaptive systems (Davids, et al., 2014). Within-individual interactions (movement coordination) display the same hallmark properties of *synergy formation under constraint* and *sensitivity to surrounding information* as those observed in between-individual relations (interpersonal interactions between teammates and with opponents) (Riley et al., 2012). In both performance contexts a key strategy is to understand the information that constrains the system's dynamics over different timescales.

Implications for Learning Design in Sport

Processes of co-adaptation in complex adaptive systems in sport are predicated on a continuous exploration of information in a performance environment as athletes search for functional task solutions. This important exploratory basis of co-adapting to changes in a performance environment can inform learning design in individual and team sports. The implication of these ideas is that the informational constraints designed into a practice task represent a most powerful influence on the emergent pattern dynamics during performance showing how the athlete-environment interactions needs to be carefully considered in *representative* practice task designs.

Representative design is a concept proposed by Ego Brunswik (e.g., 1956), which refers to the composition of experimental task constraints so that they *represent* a behavioural setting to which the results are intended to be generalised (for detailed discussions see Araújo, Davids & Passos, 2007). In ecological dynamics this concept has shaped understanding of how to design practice task constraints in learning environments which can be generalized to competitive performance constraints (Davids, 2012). *Representative learning design* is a term which theoretically captures how motor learning theorists and pedagogues might use Brunswik's (1956) insights to design practice and training task constraints that are representative of a performance context which they are intended to simulate: competitive environments in individual or team sports (Pinder et al., 2011). A key principle of ecological dynamics for the design of representative practice tasks in individual and team sports is that such simulations are based on a detailed sampling of the informational variables available in specific performance environments for athletes to use in regulating behaviours. A most important point is that representative practice tasks need to ensure that each athlete's processes of cognition, perception and action are functionally integrated during performance

(Pinder et al., 2011). Functionality of practice task design ensures that learners are able to achieve specific performance goals during practice by regulating their actions (movement responses, decision making) by using similar information sources that exist in competitive performance environments. Representative learning design in practice is predicated on the key principle that movements typically need to be coupled to specifying perceptual variables in practice tasks which simulate competitive performance environments.

Transfer conceptualised in Ecological Dynamics

Transfer is a complex topic studied for over a century, leading to much discussion, debate and disagreement over the nature of its influence on human behaviour (Barnett & Ceci, 2002). Barnett and Ceci (2002) rightly criticised the large volume of research on transfer as lacking a focus on the different dimensions of the concept. Previous work has suggested that the most important aspect of training transfer to focus attention is a *required response* in one performance condition and another. This paper addresses the concept of *transfer of training* (Issurin, 2013), which seeks to enhance the capacity of pedagogues to design functional practice tasks which faithfully simulate competitive performance environments in sport. Transfer of training (Issurin, 2013) has dimensions which are task-oriented, describing transfer as *lateral* and *vertical*. Lateral transfer refers to application of existing skills and knowledge to a range of tasks, all with similar levels of complexity and challenge. Vertical transfer refers to applying what individuals have already learned to a more complex task.

Training transfer seeks to establish what the specific effects of a practice task are on athletic performance. How does one capture this notion of specificity of transfer? According to Issurin (2013) the "transfer is characterized as the extent to which a response in one task or trained situation affects the response in another task or untrained situation." (p675). In line with this description, Issurin (2013) proposed that transfer tasks, based on requisite responses from learners, could be lateral (towards more similar tasks) and vertical (scaffolding learning in more complex tasks). This operational, task-based description of transfer is reminiscent of ideas of Barnett and Ceci (2002) who suggested that successful transfer was predicated on levels of task similarity. Their description of transfer considered the 'proximity' between tasks of the practice and performance environments, operationalised as 'near' (more similar) and 'far' (less similar). Considered together, these existing descriptions of transfer, are biased towards the specific task response required and provide an operational characteristic which may be somewhat difficult to quantify in terms of 'nearness/farness' or 'laterality/verticality'.

In contrast an ecological dynamics' perspective of transfer provides a compelling theoretical rationale to explain the process of transfer, predicated on the person-environment scale of analysis (Davids, 2012; Davids et al., 2014). In ecological dynamics, transfer is viewed as a *relationship* between the *intrinsic dynamics* (predisposition for action based on constraints such as genes, previous experience, development) of each individual athlete and the *task dynamics* (roughly the informational properties of the task to be performed) (for the original theoretical rationale see Kelso, 1995). Data have shown that when intrinsic and task dynamics cooperated (signifying that intrinsic dynamics complement task dynamics), then transfer was positive (Zanone & Kelso, 1992). If the two sets of dynamics competed (meaning that they were not complementary), then transfer was more challenging or negative (Zanone & Kelso, 1992).

An important question that ecological dynamics theoretically considers is: what transfers? According to an ecological dynamics rationale of skill acquisition, it is the *information-movement relationship* that transfers between the task constraints of a faithfully simulated practice task and a competitive performance environment (Araújo & Davids, 2010; Pinder et al., 2011). This compelling rationale indicates that the information present in the performance environment needs to be *represented* when designing a practice environment in both individual and team sports. Issurin (2013) argued that low to medium skilled individuals can gain a lot from training with general (non-specific) information sources, whereas highly skilled individuals need exposure to very specific information sources during practice. This idea resonates with the notion of designing specifying perceptual variables in practice tasks with more advanced learners and skilled athletes. This will ensure a specificity of transfer during practice which is imperative for advanced learners in team and individual sports. However, it is clear that beginners can also improve to a limited extent when they pick up non-specifying perceptual variables in practice (Jacobs & Michaels, 2007). This might emphasise the general process of transfer in which learners gain experience in integrating intentions, perception and actions.

An important feature of *transfer* in an ecological dynamics approach to skill acquisition is that it needs to ensure that intertwined processes of cognitions, perceptions and actions used by athletes during practice to regulate their behaviours (e.g., during practice in indoor climbing environments) will generalise to another performance context (e.g., outdoor climbing environments) (Araújo, Davids, & Passos, 2007; Pinder et al., 2011). Therefore, a key challenge for coaches and teachers is to ensure a behavioural correspondence between practice and performance contexts (Araújo et al., 2007). Successful transfer between a learning and performance environment can be ensured by incorporating a *representative learning design* in the former to induce functional behaviours of learners (i.e. cognitions, perceptions and actions). Pinder et al. (2011) argued that representative learning design could enhance transfer of learning if the *constraints* of training and practice environments closely simulated the ecological constraints of a performance environment, so that they allow learners to perceive affordances and couple movements to key information sources within those settings. Ensuring availability of representative affordances and behavioural correpondence in practice simulations is the key to successful transfer of functional performance behaviours from one environment to another.

This important idea was investigated in a study of traditional training practices in elite springboard diving. For example, Barris and colleagues studied preparation for take-off in an elite sample of Olympic-level springboard divers when diving into a pool and under the different task constraints of training in a dry-land facility comprising a foam pit. Elite divers tend to routinely practice in separate training environments (dry-land and pool), requiring differences in final performance outcomes, especially landing (feet first and head first, respectively). Divers seek to practise the same preparation phase, take-off and initial aerial rotation in both practice environments, although there is little empirical evidence to suggest that the tasks completed in the dry-land training environment are representative of those performed in the pool environment. The concept of conditioned coupling in ecological dynamics signifies that performance of different movement components would remain dependent on each other, and slight variations in task constraints could lead to different emergent coordination patterns (Davids, 2012). In line with these theoretical predictions, it was expected that emergent self-organisation tendencies under the two distinct task constraints would lead to differences in preparation. Barris et al. (2014) observed similar global performance features in all participants who used the same joint coordination patterns during dive take-offs completed in the dry-land and aquatic environments. However, as a group, participants showed statistically significant differences in performance at key events (second approach step, hurdle step, hurdle jump height, and board angles during the hurdle and at landing) during the preparation phase of dive take-offs completed in dry-land and aquatic training environments. For example, participants showed significantly less board angle depression at landing (from the hurdle jump) during take-offs completed in the dry-land area, than those completed in the pool.

These ideas on the relationship between carefully designing affordances in the constraints of practice tasks and the processes of transfer have also been confirmed in the context of team games. Travassos et al. (2012) examined practice task design in team sports, reporting data to show how enhancing representativeness of a practice simulation might increase opportunities for transfer in team games training. Travassos and colleagues (2012) studied Futsal players during a ball passing practice task and manipulated informational uncertainty (of passing direction) for practising players. Information uncertainty during passing practice was increased under four distinct task constraints and compared with passing behaviours observed during a competitive match. They made the plausible assumption that greater similarity of behaviours observed during practice and performance signalled the transfer of skill in passing. Intermediate level football players were required to perform simple and complex passing drills (straight vs diagonal vs diagonal and lateral passing lanes with more than one ball in use). In their study the terms 'simple' and 'complex' were differentiated by the amount of variability designed into the practice task simulations. The simple passing drill took place in a single pre-determined lane (including less environmental variability), whereas the complex passing drill involved multiple passing lanes which were emergent (pass direction emerged depending on whether the receiver had a ball or not) (including more environmental variability). Speed and accuracy of passing performance in practice tasks were compared with observations during competitive performance. Results showed the greatest similarities in passing speed and accuracy between performance in the multiple passing lane condition and actual competitive performance. There was too much regularity in ball speed and accuracy in the passing task constraints with fewer options, compared to the level observed in task constraints with more options (pre-determined vs emergent conditions). These measures showed how transfer of learning was predicated on action fidelity between skill performance in practice and competitive performance. According to Travassos et al. (2012) "…increasing the number of emergent passing actions offered in a practice task design was more representative of competitive performance" (p5). These data show how the informational constraints of practice tasks should be designed to *represent* the informational constraints of a competitive performance environment in team sports. Data revealed that, for the skilled performers, pre-determining, limited passing options did not lead to similar levels of speed and accuracy as creating emergent, multiple passing options and competitive performance. These results suggest how transfer between practice task constraints and the performance environment can be achieved in team sports training.

Conclusions

Coaches and sports teachers need to consider themselves as designers who focus on the informational constraints created in practice tasks in individual and team sports. Informational constraints or *affordances* that are constructed into practice task simulations by coaches and physical education teachers to facilitate the exploratory behaviours and interactions of athletes with their performance environments.

The implication of these ideas for sport scientists is that skill acquisition interventions need to be based on empirical verification of information sources used by athletes to support their actions. An important task is to ascertain how these sources need to be *represented* in simulated practice environments. The criteria to develop an operational definition of "representative learning design" should include the following (Araújo et al., 2007, Pinder et al., 2011):

1. Designing tasks in a perceptual-motor workspace of practice so that perceiving information that specify a property of interest (e.g., the movement interactions between an attacker and defender specifies affordances "invited action opportunities" such as dribbling into a gap or moving to close a gap). This aspect of learning design should allow learners to make reliable judgements and actions about environmental properties such as values of interpersonal distance between an attacker and a defender,

2. Creating learning tasks that include situations which continuously evolve over time, requiring interrelated decisions and actions, so that athletes learn to perceive and utilise affordances for regulating behaviours,

3. Designing tasks that enable learners to act in context in order to detect affordances to support achievement of their performance goals,

4. An important implication of these ideas is that the perceptual-motor workspace of practice can be modified through constraint manipulation to increase the exploration of emergent adaptive behaviours in individuals. It can be expected that placing individuals in a well-designed perceptual-motor workspace, operationalized by principled constraints manipulation, will increase exploration and exploitation of inherent coordination tendencies, enhancing the capacity for movement adaptation (Davids, 2012).

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