This chapter provides an account of how expertise in sport is acquired, from the framework of ecological dynamics. Ecological dynamics research has shown that expert performance in sport is predicated on an athlete’s capacity to functionally adapt his/her movements to the dynamics of complex performance environments by continuously perceiving information to regulate goal-directed actions. Here we selectively focus on the contribution of three key theoretical ideas from ecological dynamics: perceptual attunement to affordances, harnessing neurobiological system degeneracy, and exploiting adaptive movement variability in a metastable system state. We relate these ideas to practical examples from sport performance throughout, discussing how they might inform the design of practice strategies.

The ecological dynamics perspective on expert performance in sport and the acquisition of expertise

Ecological dynamics emphasizes the study of organism–environment systems, a central theme in ecological science. Ecological science is committed to studying information-based behavioral transactions between individual organisms, and between individual organisms and relevant properties of a specific performance environment, including objects, surfaces, terrains, and niches that comprise the physical surroundings. Within an ecological dynamics approach, organisms and their performance environments form complex and dynamical systems, characterized by continuous interactions between key system components, and continuous change or activity across different timescales (Davids et al., 2013; Davids et al., 2014). These key ideas have important implications for considering expertise in sport since ecological dynamics is concerned with understanding the relationship between an athlete and key properties of a performance environment. Relevant properties complement physical characteristics, psychological, emotional, and social processes which continuously constrain athlete–environment interactions (Chow, 2013; Seifert et al., 2013a). In addressing this complexity, ecological dynamics integrates ecological psychology and dynamical systems theory for understanding a performer’s intentional actions with respect to a performance environment (Araújo et al., 2006).
Expert performance in sport

Ecological psychology

Ecological dynamics emphasizes the mutually constraining relations between perceptual and action subsystems in humans for coordinating action (Gibson, 1979). To exemplify, in the sport of long jumping, light reaches the eyes of a jumper after being reflected off surrounding objects and surfaces – the takeoff board, the pit, a windsock placed near the jumping area – providing each performer with information for regulating stride adjustments during the run-up and jump preparation phases of performance (Greenwood et al., 2013). The organization of functional performance behaviors is underpinned by dynamically intertwined relations between intentions, perception, and action in each individual. During performance, an individual’s intended movements generate perceptual information, which, in turn, constrains the emergence of further movements. For example, information perceived by a basketball player on court is constrained by specific actions (e.g., when dribbling or defending) and by intentions (e.g., to play conservatively or to take risks) (Cordovil et al., 2009). In climbing, Seifert and colleagues (2014) observed how skilled climbers perceived different properties of ice surface structure to adapt their actions with ice tools and crampons. When they perceived holes in the ice surface left by previous climbers, hooking actions emerged. Conversely, when the ice was smooth and dense, the climbers used swinging actions to create the holes needed for a safe and rapid traversal. In turn, a climber’s movements continuously change his/her relationship with the performance environment and create information for new action opportunities. Seifert and coworkers (2014) reported that skilled climbers used a large range of actions, including movement coordination patterns that crossed two limbs, leading them to detect different sources of kinesthetic information, and supporting different body positions on the ice to maintain equilibrium and achieve a traversal. For instance, symmetric use of limbs with ice tools and crampons led them to adopt X-shaped body positions, which faced the ice surface. When they sought asymmetric anchorages on the icefall, more functional side-to-the-icefall body positions emerged.

These examples demonstrate Gibson’s (1979) insights on the importance of maintaining relationships between key sources of information and actions through carefully structured practice strategies for developing experts. Different sources of perceptual information present opportunities for different performers to execute specific actions in sport. These actions in turn create information that supports further goal-directed behaviors in a cyclical fashion. For this reason, practice task design must simulate the ecological constraints of performance (see Withagen et al., 2012). In doing so, a major aim of pedagogists – i.e., achieving behavioral correspondence between learning and performance environments – can be met and should enhance the development of expertise in sport (Pinder et al., 2011a, 2011b). In the development of expertise in sport these ideas suggest that practicing athletes need to be given opportunities to search for and use information to guide their actions. This is best achieved through practice tasks that allow continuous movement interactions (not static drills), opportunities for exploration of the performance environment (not prescription of a specific movement pattern to imitate), and inclusion of key information sources that will be present during performance (e.g., other players in team games [Orth et al., 2014] and relevant court/pitch markings [Headrick et al., 2012]).

Dynamical systems theory

A second important constituent of ecological dynamics is dynamical systems theory, a multidisciplinary, systems-led approach encompassing mathematics and physics, and their extensions to biology and psychology. In this theory, natural phenomena can be explained, at multiple scales
of analysis, with the same underlying, abstract principles, regardless of a system’s structure and composition (e.g., the coordination of a player’s movements and a team’s attacking and defensive play can be understood through analyzing system changes over space and time). These key ideas are instrumental in capturing how the continuous coupling (coadaptation) between a performer and a performance environment can be formally modeled, theoretically conceptualized, and empirically studied. Warren (2006) proposed the term behavioral dynamics to capture the ongoing spatial and temporal characteristics of the coordination between an individual and an environment. His ideas have been extrapolated to the study of movement coordination and control and the acquisition of expertise in sport (Davids et al., 2008; Davids et al., 2003; Handford et al., 1997). Understanding the continuous coupling, and adaptation, of information and actions has been stimulated by theoretical insights of Bernstein (1967). He drew attention to how

Figure 12.1 An example of how practice constraints act as information to influence behavior during performance, shaping the regulation of action. Panels A, B, and C show an experimental design detailed in Orth et al. (2014). In this experiment, eight soccer players were asked to, from a standing start, run along the sideline of a soccer field toward the byline, where a ball was positioned, and make a pass back to a receiving player at the penalty spot. They did this under three different conditions, a total of four trials each condition for each individual. Panel A shows Condition 1, where there was no defender present during the performance. Panel B shows Condition 2, where a defender was positioned at a relatively far distance and instructed to shut down the attacker. Panel C shows Condition 3, where a defender was positioned at a relatively close distance. Panel D shows the average running speed of the players. This data shows how only when the defender was near did running velocity of the attacker increase significantly. Panel E shows the overall average foot-to-ball distance standard deviation of the attacking players for each condition. Importantly, regulation was induced by the mere presence of a defender, even without the need for players to run faster. The data exemplifies how movement variability is sensitive to environmental sources of information embedded within performance contexts, and in the sport performance context is not just a form of internally produced noise incurred by maximal efforts. For reasons such as these, in ecological dynamics it is the performer-environment informational relationship that is emphasized for driving pedagogical practice. Note: A = attacker; B = ball; D = defender; GK = goalkeeper; m = meters; m/s = meters per second; R = receiver; # = significant main effect; * = significant between condition effect.
the abundance of motor system degrees of freedom can be exploited by continual (re)organization during goal-directed performance (Bernstein, 1967). Ecological dynamics emphasizes the importance of developing experts being required to continuously reorganize and coadapt their actions, perception, and cognitions as they seek to achieve their specific task goals (in team sports these include keeping possession of the ball, attempting to score, covering teammates and space, and dribbling). The continuous reorganization of system degrees of freedom is not driven by the environment. As Whiting (1991) once succinctly captured the coordination problem in sport: action is not reaction! Coordination of movement and between individuals in a performance environment emerges from their coadaptive behaviors (Davids et al., 2012).

In this systems approach, many biomechanical degrees of freedom are available for movement regulation, demonstrating the wealth of options available to the central nervous system for motor task performance (Davids et al., 2006; Davids & Glazier, 2010). The abundance of system degrees of freedom is simultaneously a wonderful resource to be exploited by an athlete and an organizational challenge for a performer’s central nervous system during skill acquisition (Davids & Glazier, 2010). The number of motor system degrees of freedom to be regulated by an individual changes significantly with the increasing complexity of an action to be coordinated, exemplified by the difference in performing a forward entry dive into a pool and the performance of a backward three-and-a-half somersault from a 3 m springboard (Barris et al., 2013a). At a different scale of analysis, coordination between players in a team also involves the continuous (re)organization of the team’s degrees of freedom (individual players) when attacking and defending together. However, the creation of synergies between the component parts of the body and between the team players provides the functional means for task goals to be achieved through coordination (Wu & Latash, 2014).

In ecological dynamics, expertise in sport is revealed by functional coordination solutions that are assembled from system components by individual athletes to satisfy the unique set of constraints interacting upon him/her (Davids et al., 2008). From this perspective, the physical characteristics of the performance environment, the morphology of each individual’s body, information variables, and specific task constraints all interact to constrain goal-directed activity (Araújo et al., 2004; Warren, 2006). Due to these continuous interactions, explanations of expertise, based solely on either personal (e.g., genes or psychological processes) or environmental constraints (e.g., amount of practice undertaken), are fundamentally limited (Baker & Davids, 2006). Some current estimations suggest, for example, that between 22 to 36 per cent of performance variance can be explained by genetic constraints (Phillips et al., 2010; Simonton, 2007). Research on physical activity, exercise, and sport performance displays little support for either biologically or environmentally deterministic perspectives (Baker & Davids, 2006).

**Skill acquisition and expert performance in sport**

Our research suggests that traditional theories of skill acquisition tend to overvalue the importance of repetition of an ideal movement pattern (e.g., Adams, 1971; Ericsson et al., 1993; Gentile, 1972). There has been considerable criticism of the notion that a putative “common optimal movement” pattern exists (see Brisson & Alain, 1996; Schöllhorn et al., 2006). The belief that expert performance can be achieved through constant rehearsal of an idealized movement pattern (e.g., a classical technique) is pervasive in many sports (Seifert et al., 2013a). It is exemplified by the erroneous obsession that some coaches have with the acquisition of a specific set of mechanics for the golf swing, to be perfected through hours of practice under the constant conditions of a golf driving range. It is also instantiated in the perception of elite springboard divers, that preparatory movements (the hurdle step), considered less than ideal, should be terminated through
“baulking,” discontinuation of the aerial and water entry phases of the dive (Barris et al., 2013b). Conversely, evidence shows that baulking, especially in the absence of a perceived injury risk, can be considered a maladaptive behavior by the athlete because it leads to penalty points in the competitive environment, inhibits the diver from experiencing how to adapt ongoing movements to a varied, initial hurdle step, and can lead to a loss of hundreds of practice trials each week (Barris et al., 2013a; Barris et al., 2014).

In ecological dynamics, the capacity to adapt movements to dynamic interacting constraints of a performance environment, to achieve specific intentions and make decisions, broadly defines expertise (Davids et al., 2008; Seifert et al., 2013a). From a constraints-led perspective, skill acquisition is proposed as a search for functional coordination solutions that emerge from individual, task-oriented, and environmental constraints (Newell, 1986). Expert performance is captured by the emergence of an increasingly more functional athlete-environment relationship acquired over time with task experience (Davids et al., 2008). This view of skill and expertise as a more functional relationship is distinct from theories that emphasize the repetition of a particular movement pattern or coordination mode through constant practice. It recognizes the need for each individual learner to adapt to, and satisfy, the unique array of interaction constraints impinging on him/her at a specific stage of development and level of experience. Expert performers are able to constantly (and subtly) reinvent themselves as key constraints change; that is, as new opponents set unique challenges, as rules change, as equipment evolves, and as maturation and aging affects the systems of each athlete’s body (see Figure 12.2 for a summary).

The role of adaptive capacities in expert sport performance is reflected in the variety of behaviors that highly skilled athletes can display during performance and their ability to vary

![Figure 12.2](image-url) Exemplifies both how performance emerges from constraints on performer-environment relationships, and how performance environments might evolve over time relative to the skills of the individual. A characteristic of the development of expertise is that it evolves over an extended timescale, providing a basis where skills can influence the different contexts that individuals perform under. As skill evolves, individuals might experience new environmental properties (for example, rock, snow, ice) and equipment (safety equipment, icepicks). Such potential diversity in experiences leads to highly unique individual adaption, and some underpinning features of the learning process somehow allow expert performers to constantly reinvent themselves so that they may transfer their skills into highly demanding performance contexts where key constraints can change in highly unpredictable ways.
Expert performance in sport

those behaviors from trial to trial to achieve similar performance outcomes (Seifert et al., 2013a). Adaptive movement variability provides individuals with the capacity to maintain performance outcome stability in the face of perturbations within dynamic performance environments (e.g., successfully driving a golf ball to an intended playing area on different course layouts or in varied weather conditions). These ideas imply that an important practice strategy should be to compose a perceptual-motor workspace within which (developing) experts can search for functional coordination solutions, rather than require them to rehearse putative, “ideal” movement techniques. As we discuss next, this functional practice strategy should include the design of affordances, the enhancement of adaptive behaviors through harnessing inherent degeneracy in human movement systems, and aid to exploit system metastability.

Key aspects of expert performance in sport: attunement to affordances, harnessing neurobiological system degeneracy, and exploiting metastability during learning

Perceptual attunement to affordances

The theory of affordances was conceived by Gibson (1979) to explain how organisms detect information and perceive properties of their environment that can be used to regulate their decisions and actions. Affordances are opportunities for action that can selectively invite behaviours of an individual in a specific performance environment (Withagen & Chemero, 2012). The key relationship between the physical properties of a performance environment and an individual's action capabilities provides a veritable landscape of affordances in sport (e.g., the trajectory of a ball to catch, hit, or avoid, or a gap to dribble through). As he/she acquires expertise, the performer becomes attuned to affordances that can support achievement of performance goals in specific circumstances. The ability to perceive an affordance is predicated on an individual's ability to detect information in a performance environment relative to his/her existing action capabilities (e.g., whether a hold on a rock affords a vertical pinch hand-grasp or horizontal crimp hand-grasp action for a climber during a traversal, Phillips et al., 2012).

To underline the notion that the relations between an individual and a performance environment constitute affordances (i.e., they are not an entity to be memorized), Gibson (1966) distinguished between knowledge of and knowledge about the environment. He proposed that knowledge about the environment involves perception, which is indirect or mediated by language, symbols, pictures, and verbal instructions, all of which can facilitate analogical reasoning and verbal communication of what an information source means. This is the type of knowledge used when coaches verbally instruct an athlete on how to perform a movement pattern or about a defensive formation to adopt in a team game like water polo. Knowledge of the environment, in contrast, describes how a biological organism can perceive the surrounding layout of its performance environment in the scale of its body and action capabilities (Turvey & Shaw, 1995, 1999). According to Gibson (1966), knowledge of the environment facilitates the completion of an action in a performance environment because it involves the perception of invariants used to control action directly. To exemplify, knowledge of the environment in water polo involves the pickup of perceptual variables that specify properties of a ball skidding on the water surface, which selectively constrain functional behaviors, such as gripping with wet fingers or hitting with the hand. These behaviors are functional for performance behaviors such as keeping possession of the ball or defending a shot in the pool (see also Araújo et al., 2009 for applications to basketball). Seifert and colleagues (2014) showed how expert climbers tended to use subtle combinations of kinesthetic, haptic, acoustic, and visual information to regulate their actions, while beginners were
dominated by one source of information. To maintain stability on an ice surface, beginners in climbing typically rely on information from depth of an ice tool blade entering the frozen icefall, while experts perceive haptic information from vibration from the ice tool, acoustic feedback from the sound of the blade, and vision of the anchorage. Beginners also showed less perceptual attunement to environmental properties than experts, displaying a global perception of environment properties, which does not specify action accurately. For instance, in ice climbing, whereas experts can distinguish information from the handle and blade of the ice tools, beginners only take into account the ice tool globally. Their global perception of their relationship with the performance environment cannot specify how information from separate parts of the ice tool can interact with the dynamics of the icefall, including ice thickness, steepness, and density, as they alter during an ascent.

Warren (2006) exemplified how affordances are relational in humans, demonstrating how they remain available over a range of spatiotemporal values of a variable. What this signifies is that the same object, event, or surface can selectively invite different behaviors of the same performer over time and, of course, different behaviors from different individuals (Withagen & Chemero, 2012). Warren (1984) proposed that, at extremes on the spatiotemporal scale that represent the limits of an affordance, there corresponds a boundary region beyond which an organism must perceive a different affordance in order to interact with the environment as intended. During learning, a number of different body–environment relationships can be facilitated to emerge in practice, and these relationships are predicated on the scalable relations between specific personal constraints (such as body dimensions [Hristovski et al., 2006] and action capabilities [Orth et al., 2014]) and environmental properties. To enhance expertise in sport, a suitable strategy is to modify practice tasks for different learners to help them probe the boundaries between affordances. To exemplify, on a tennis court the acquisition of skill in the backhand volley might be facilitated by designing different affordances into a practice rally between a player and coach/training partner. Different types of feeds by a coach afford the performance of different shots by a specific athlete. In some feeds a backhand or forehand drive may emerge from a tennis player and under specific task constraints (a specific ball trajectory relative to the practicing player) the backhand volley will emerge. There is rarely a need for verbal specification of the “correct” (most functional) shot to play under different competitive constraints, and a skilled coach will not specify a shot afforded to a developing expert in a specific game situation. Specific strokes emerge as a developing expert gains knowledge of a performance environment through perceiving an affordance of a ball in flight and acting upon it (Carvalho et al., 2013). A specific affordance will selectively emerge in game situations based on the individual constraints of each athlete (differentiated by speed on the ground, anticipation, arm span and reach, and tactical intentions), exemplifying how cognitions, actions, and perceptions are intertwined to achieve performance goals.

This idea clarifies how constraint manipulation forms the basis of practice design in sport. This pedagogical approach can enhance expertise by the creation of a perceptual–motor landscape in which specific actions are more likely to emerge from individuals. In this respect, a learning environment should not be considered as a “neutral” landscape of possibilities. Rather, the design of particular opportunities for action can be potentiated by inviting actions from individual learners (Withagen et al., 2012). Perceptual–motor landscape (affordance) design by coaches in sport is driven by questions such as: what performance aspects need to be strengthened? What information–movement couplings need to be emphasized in affordance design? How can a performer or team coadapt to the specific tactical strategies of opponents? Key phases in learning to pick up affordances to regulate actions include the education of intention, the education of attention, and calibration. Perceptual attunement occurs during expertise development when athletes learn to
distinguish which sources of information to attend to in which specific performance situations, and also when to attend to these perceptual variables.

Here we can consider these theoretical ideas by considering a basic problem in ball sports: when and how long to watch a ball in flight to organize an interceptive action. With extended practice, developing players converge from sources of information that may be less useful in one specific situation to perceptual variables that are more useful under a range of different performance circumstances. For example, early in learning, many ball players keep their eyes on the ball (e.g., a batter in cricket watching ball flight to strike the ball). As expertise in a sport is enhanced, a player becomes attuned to a wider range of spatial and temporal perceptual variables and gains a greater sensitivity to the contextual consequences of his/her actions (Araújo et al., 2006). Later in learning, cricketers begin to converge on more useful information from a bowler, such as body orientation, arm position, and hand adjustments prior to ball release (Pinder et al., 2011b).

This process of perceptual attunement is supported by system degeneracy – the ability of elements that are structurally different to perform a similar function or yield a similar output, an essential feature of skilled behaviour (Edelman & Gally, 2001; Mason, 2010). For instance, research has established how expert players in field hockey reach the same performance outcomes (e.g., ball velocity) with different movement patterns (Brétigny et al., 2011). In particular, they exhibited kinematic differences in relation to their role on the field (defenders versus midfielders and forwards): forwards used a shorter backswing duration than defenders, which is a real advantage in contexts of temporal pressure as movement preparation time is shortened and prevents any risk of ball interception (Brétigny et al., 2011).

After perceptual attunement is enhanced, the developing expert undergoes calibration, or the scaling of the perceptual-motor system to information. In these individuals, body dimensions and action capabilities are not static, but often change due to development, aging, and/or training. When body dimensions and action capabilities change, actions that were once impossible may become possible (or vice versa, see Fajen et al., 2008). These ideas illustrate the importance of recognizing individual differences in the way that skilled performers achieve functional task solutions. For example, as young adults, tennis players can reach passing ball trajectories to volley rather than having to wait for the ball to bounce to drive it. With aging, system reorganization in older adult players might signify that letting a ball bounce for a drive is a more functional shot than striving to volley a passing ball early. This example also highlights how athletes’ effective body dimensions can be mediated by using equipment in sport such as racquets, roller blades, bats, and sticks. In acquiring expertise, constant calibration and recalibration are necessary to establish and update the mapping between the relevant properties of the world that are perceived, and the actions achieved. Calibration during extensive periods of practice makes it possible for performers to perceive the world in intrinsic units (e.g., related to their individual limb segment dimensions), even after changes in body dimensions and action capabilities due to development, training, and growth. For a calibrated performer, body-scaled and action-scaled affordances can be directly and reliably perceived by simply picking up the relevant sources of information to regulate actions (Fajen et al., 2008). Although recalibration occurs quite rapidly, it is likely that continued experience leads to further refinement in calibration. Affordances that are both body and action scaled become more prevalent in sport, as expertise is enhanced. Processes like education of intention, attunement, and calibration can occur at all phases of expertise development.

Intentions selectively change as a function of experience, suggesting that attention will shift to different information sources throughout the learning process (Davids et al., 2012; Jacobs & Michaels, 2007). For example, in sports like swimming and mountain biking, although a major competitive goal might be the rapid displacement across the aquatic environment or forest track, a novice’s intentions are primarily to avoid sinking in a pool or falling off a bike. As skill level and
expertise changes, specific intentions and performance goals are likely to change radically too, such as via a prospective control process (Montagne, 2005) or conditioned coupling (Van Geert, 1994). For instance, Seifert et al. (2011) showed high inter-individual variability of coordination patterns in novice swimmers that could relate to an exploratory phase with regard to environmental constraints: they experience the Archimedes’s principle by dealing with constraints of gravity and buoyancy, captured by Newton’s third law of producing an action to get a reaction in the opposite direction. These novice behaviors may relate to various intentions for the same task goal; in particular, the priority of novice swimmers is not only to advance in the water, but also to balance (stay in a ventral position), float (stay at the water surface), breathe (avoid bringing hands to the chest in order to keep the head above water), and perceive the layout of the aquatic environment (Newton’s law and Archimedes’s principle). Later in learning, expert swimmers become more attuned to information, helping them to swim quickly and economically (Seifert et al., 2011). These examples show how different ways of achieving performance are featured in both the movement system and in environmental properties. Ecological dynamics conceptualizes this variability in behavior for achieving the same outcomes as a reflection of inherent system degeneracy. We now consider how degeneracy provides a functional explanation for behavioural variability shown in expert movement coordination.

Harnessing inherent degeneracy in neurobiological systems

Degeneracy exists at all levels of neurobiological systems (e.g., genetic, neuronal, perceptual, musculo-skeletal) and emerges when components differing in structure achieve a similar function in an environmental context (Edelman & Gally, 2001). Mason proposed that degeneracy exists in systems “where structurally different components perform a similar, but not necessarily identical, function with respect to context” (2010, p. 277). This conceptualization of degeneracy emphasizes the important role of movement variability in achieving performance outcomes, implying a shift away from a normative categorization of an action as, for example, a “classic technique” in sport. Degeneracy is a functional property because it provides neurobiological systems with flexibility and variability, which is adaptive, enhancing their resistance to internal and external perturbations. In human movement systems, degeneracy infers how the same function can be achieved by two different biomechanical architectures, each involving different joints (i.e., many structures-to-one function), as well as by several joints working together (i.e., one structure-to-many functions), whilst leaving some joints free for future involvement (Seifert et al., 2013a; Mason, 2010).

Degeneracy signifies how an individual can vary movement behavior (structurally) without compromising function and is an important aspect of skilled sport performance. It has been investigated in a range of sport-related activities, including simulated skiing (Nourrit et al., 2003), riding a pedalo (Chen et al., 2005), basketball shooting (Rein et al., 2010), soccer kicking (Chow et al., 2008), and breaststroke swimming (Komar et al., 2014). Degeneracy supports the functional robustness and adaptability of human movement systems, providing a compelling explanation why variation in perceptual-motor behaviors is needed within and across individuals during goal-directed activities. Our work has shown that it is an important characteristic to exploit in becoming expert in sport (Chow et al., 2011; Chow, 2013).

Exploiting neurobiological degeneracy requires the performer to continuously seek to (re)establish coordinated relations amongst limbs, joints and environmental surfaces, objects and events in a performance environment, regulated by different perceptual variables. For example, numerous effector systems (limbs) may be (re)assembled in several distinct ways to resolve the same task outcome or adapt to variations in the task demands (such as in performance conditions
when advanced information for actions are hidden by opponents or disguised for deception) (Davids & Araújo, 2010). Examples of the functionality of degeneracy in sport are endless and include: (i) in tennis, a backhand or forehand stroke in a rally can be achieved by using one hand or two hands; (ii) in football, a defensive interception can be achieved by heading the ball, sliding through the ball with the left or right foot, using the body to block a shot, or “nicking” the ball with a toe end (a goalkeeper might use his/her head, hands, body, and feet in defending a shot); (iii) excellent teams use degeneracy by varying their offensive and defensive patterns to coadapt to performance conditions (small or large fields, weather conditions) and especially opposition tactical changes (strengths and weaknesses); and (iv), in judo, when rule changes in permitted gripping actions occur, the same throws are being observed during competition, but with modified grips by performers.

In seeking to become expert, athletes can exploit inherent system degeneracy to achieve their task objectives by strategically (re)stabilizing or destabilizing their coupling of movement and information. Over extended timescales system degeneracy provides a platform for individuals to discover new affordances and restabilize information-movement couplings, leading to expectations that different coordination solutions might selectively emerge to achieve the same performance outcomes through exploratory practice. The role of practice in exploiting degeneracy can be helpful for athletes to generate new coordination solutions as well as adapt existing movement patterns so that they satisfy the constraints of a particular performance context (Barris et al., 2013). If individuals were to over-practice under fixed task and environmental constraints (e.g., driving a golf ball at a driving range or baulking when preparing to dive from a springboard), the acquisition of expertise would be hindered by lack of opportunities to continuously coadapt movement patterns to changing environmental constraints. Constraint manipulation by skilled coaches can induce learning to promote exploration and adaptation in a systematic manner, enhancing the dexterity of an athlete, a most significant property of expertise in sport. Newell (1996) recognized the importance of Bernstein’s insights that movement expertise is predicated on dexterity; that is, “… the capacity to solve a motor problem – correctly, quickly, rationally, and resourcefully. Dexterity is finding a motor solution for any situation and in any condition … ” (1967, p. 398). In sport, expertise is not expressed by the capacity to repeat an idealized movement pattern in an identical way from trial to trial, but rather by the achievement of functional coordination solutions in dynamic performance environments.

This key idea in ecological dynamics provides the basis for a theoretically principled and pragmatic approach to progressive, long-term, sustained skill acquisition at all performance levels in the progression from novice to expert status (Davids et al., 2012). Under the constraints-based framework, expertise development can be enhanced by identifying affordances as selective constraints on an individual’s learning and managing these effectively with respect to interactions in the learning environment. Early in learning, an aspiring expert begins to explore information-movement couplings that allow patterns of coordination to remain stable under perturbation.

**Exploiting system metastability**

Inducing functional exploration is needed to enhance coordination and control. This aspect of expert performance can be achieved through modifying key constraints that act on the dynamic, spatiotemporal relationships that individuals form during performance. An important goal for sport pedagogists is to help learners explore system metastability. Metastability involves switching between (and stabilizing) different functional coordination tendencies to achieve performance goals. For example, in ball sports like cricket and tennis, experts can switch between equally...
functional strokes to achieve a specific performance goal of defending against, or attacking, the opposition (for an example, see Figure 12.3 that summarizes the work in Pinder et al., 2012). In a metastable system state, multiple information-movement couplings functionally coexist under the same constraints and are expressed randomly from trial to trial. Metastability exists when, under the same constraints, there is the coexistence of segregating tendencies (for action to be performed relatively independently of the environment) and of integrating tendencies (for action to be performed relatively dependently on the environment) (Kelso, 2012). There is no constant force stemming from either the performer’s personal constraints (intrinsic dynamics) or task constraints that requires performance behavior to reflect a fixed stable state. Metastable regimes in practice support the emergence of rich and variable patterns of behavior that are functional (e.g., support task success, help adaptation, and uncover new information).

Although theoretically conceptualized as a mechanism for learning, the role of metastability in learning complex, goal-directed behaviors has rarely been operationalized, or tested in sport (Chow et al., 2011). It has been operationalized in a study of striking a heavy bag in boxing and in analysis of a defensive stroke in cricket batting (Hristovski et al., 2006; Pinder et al., 2012). The notion of a metastable regime can be exemplified in the sport of climbing and operationally defined by the trial-to-trial dynamics of (i) body-wall coordination patterns and (ii) “technical” perceptual-motor actions that regulate the stability of the body-wall orientations used for surface traversal. Under a metastable regime in climbing, the individual learner should be capable of...
expressing coordination patterns that are intrinsically stable, as well as patterns that are relatively novel but highly functional for adapting performance to dynamic, environmental constraints (Seifert et al., 2013b). An individual placed in a metastable regime has the opportunity to explore a variety of movement control strategies. Some strategies might be highly predictive (based on preplanned intentions), others responsive to ongoing dynamical constraints of a performance environment (based on external environmental information). With increasing expertise, athletes are neither too reactive in their response to environmental information sources, nor too pre-organized in their actions. For example, in competitive climbing, while there is some value in previewing climbing surfaces from the ground in order to consider potential traversal routes, ultimately climbing actions are emergent as affordances of specific surface holds are perceived during performance.

Summary: the characteristics of expertise in sport

In this chapter we provided an ecological dynamics rationale for understanding expertise in sport, discussing three key ideas for enhancing expertise. The main characteristics of expert performance from this perspective include:

1. The view that processes of cognition, perception, and action are intertwined in a complex way as expert performers switch between dependence on and independence of environmental information sources in performance (see point 5 below). Preferred coordination tendencies are harnessed during performance, but experts are not locked in to specific environmental constraints (in a reactive manner) during performance. Their actions can be guided by a combination of intentions and the perception of specific information sources to perform an activity in a particular way to achieve specific performance goals.

2. An important aspect of expert behavior is the capacity to perceive affordances by learning to detect key sources of environmental information that support successful task performance. Expertise can be enhanced by pedagogists’ understanding of how to design affordances into learning programs.

3. Individual differences are paramount as personal constraints of expert performers are satisfied in achieving task performance goals in different ways (see point 6 below). The influence of personal constraints eschews the notion of a common, optimal movement pattern towards which all performers should aspire, because affordances are uniquely body scaled and action scaled for each individual expert athlete.

4. Expert performance is characterized by a subtle blend of stability and flexibility that results in adaptive movement variability. Variability is only functional and adaptive when an individual is able to exploit system flexibility and stability, as and when needed, to achieve successful performance outcomes. This idea signifies that either stable or flexible movement patterns can be adopted when required, so some aspects of movement coordination can remain stable while other components can exhibit greater flexibility. This capacity captures how system degeneracy is harnessed by expert individuals (again, see point 6 below).

5. Since an expert’s emergent actions are continuously regulated by the intertwined processes of intentions, perceptions, and action, they are neither completely dependent on environmental information (reactive, completely information driven) nor completely independent of environmental information (whole movement configurations planned in advance of an unfolding situation because these prescribed action plans are weakly stable). This capacity of expertise is predicated on system metastability, which underpins creative and adaptive performance in sport.
The adaptability of actions harnesses the neurobiological system property of degeneracy, which can be exploited to allow individuals to achieve the same performance outcomes using different coordination patterns.

An important practical implication of the three key ideas discussed in this ecological dynamics explanation of expertise acquisition in sport is that in experimental work on expert performance or during expert practice programs, task constraints need to be representative of a performance environment and contain opportunities for emergent actions that are functionally adaptive, and not prescribed in advance by experimenters or coaches.

References

Expert performance in sport


