The development of decision making skill in sport: an ecological dynamics perspective

Araújo, Duarte\(^{(1)}\); Davids, Keith\(^{(3)}\); Jia Yi Chow\(^{(4)}\); Passos, Pedro\(^{(1)}\)\(^{(2)}\)

\(^{(1)}\) Faculty of Human Kinetics/Technical University of Lisbon, \(^{(2)}\) Lusófona University of Humanities and Technologies, \(^{(3)}\) Queensland University of Technology, \(^{(4)}\) Physical Education and Sports Science, National Institute of Education, Nanyang Technological University, Singapore
Abstract

In this chapter we introduce a theoretical framework for studying decision making in sport, the ecological dynamics approach, which we integrate with key ideas from the literature on learning complex motor skills. Our analysis includes insights from Bernstein (1967) on the coordination of degrees of freedom and Newell’s (1985) model of motor learning. We particularly focus on the role of perceptual degrees of freedom advocated in an ecological approach to learning. In introducing this framework to readers we contrast this perspective with more traditional models of decision making. Finally, we propose some implications for training decision making skill in sport.
Introduction

Accurate perception, action and decision-making are characteristics of expert performance in sport (Hodges, Starkes & MacMahon, 2006; Starkes & Ericsson, 2003). Although skill-related differences in these processes have been observed in research, the underlying reasons for these differences are largely unknown (Starkes & Ericsson, 2003). Typical responses for studying skill acquisition include characteristics such as reaction time, and movement rate, amplitude, and duration, rather than the detailed structure of action and the learning process (Newell et al., 2001; 2003, see also Jacobs & Michaels, 2007). In this paper we discuss the structure of learning processes in developing decision making skill in a principled way.

In cognitive science it is presumed that decision making behavior is predicated on the existence of a centralized controller—a schema or mental model that is responsible for its organization and regulation. However, this suggestion is unsatisfactory because it merely displaces the original problem of behavioral decision making to a pre-existing internal structure, begging the question why that particular neurobiological organization developed and how that specific structure originated (Turvey et al., 1981). Rather Gibson (1979) suggested that, rather than being localized in an internal structure, control of decision making is actually distributed over the agent–environment system.

This different view suggests that the structure and physics of the environment, the biomechanics of each individual’s body, perceptual information about informational variables, and specific task demands all serve to constrain behavior as it is expressed (Warren, 2006). Adaptive behavior, rather than being imposed by a pre-existing structure, emerges from this confluence of a range of personal and environmental constraints under the boundary condition of a particular task or goal (Araújo et al., 2004, Davids et al., 2007). From this perspective, the role of information and intentionality in decision making and
action can be understood in physical terms (i.e., a law-based understanding of discrete and
dynamic aspects of human behavior) (see Shaw, 2001; Shaw & Turvey, 1999; see Araújo et
al., 2006 for an application in sport).

A major challenge for the ecological dynamics approach is to understand how each
individual learns to perceive the surrounding layout of the performance environment in the
scale of his/her body and action capabilities (Turvey & Shaw, 1995, 1999). The aim of
ecological learning theories is to explain how perceivers take advantage of the informational
richness of environmental properties (e.g., E. Gibson & Pick, 2000; Jacobs & Michaels,
2007). The ecological approach to learning originated with the rejection of enrichment
theories of learning (J. Gibson & E. Gibson, 1955). In enrichment theories, stimulus variables
are necessarily ambiguous with respect to the environment; perceivers are said to resolve
ambiguity by enriching information-poor stimuli through processes such as inference or with
memories. Enrichment theories portray the emergence of expertise as an increase in
sophistication of the enrichment processes (Jacobs & Michaels, 2007).

Ecological theories, in contrast, hold that learning results in changes in the
environmental properties to which perceptual systems are sensitive (Jacobs & Michaels,
2007). The sophistication of expert performance derives from the improved fit of experts to
their environments, rather than from an increased complexity of computational and memorial
processes (Shaw, 2003). We next elaborate on this ecological framework and discuss how
skill in decision making is developed. Later, we discuss some implications for enhancing
decision-making skill in sport.

**Ecological dynamics of decision making**

There are two complementary attributes of accurate and functional performance in
dynamic environments (Warren, 2006): *stability and flexibility*. On the one hand, successful
performance is characterized by stable and reproducible low-dimensional patterns, which are functional actions consistently reproducible over time and resistant to perturbation. On the other hand, “behavior is not stereotyped and rigid but flexible and adaptive” (Warren, 2006, pp. 359). Although action patterns exhibit regular morphologies, skilled performers are not locked into rigidly stable solutions (e.g. technical, tactical) but can modulate their behaviors. Successful performers need to adapt their actions to dynamically shifting environments that characterise competitive sport. Such requisite flexibility is tailored to current environmental conditions and task demands, and implicates perceptual control of action (Araújo et al., 2006). In line with this argument, Kelso and Engström (2006) argued that transitions among stable states of organisation occur as a result of neurobiological dynamic instability, which provides a universal decision-making platform for switching between and selecting among different states order. So, if more functional movement patterns emerge to fit the circumstances and context of a performance setting, fluctuations in dynamic instabilities will help the performer discover and explore them. Importantly, this is not to be necessarily construed as a complete switch in movement systems, per se, but more as qualitative changes that arise due to the intrinsic nonlinearity of the action pattern dynamics.

Moreover, agent–environment interactions give rise to emergent behavior that has a dynamics of its own, which Fajen and Warren (2003) call behavioral dynamics. According to Warren (2006) the core claim is that stable behavioral solutions correspond to attractors in a landscape of behavioral dynamics, and transitions between behavioral patterns correspond to bifurcations. Bifurcations provide a selection mechanism, the means to decide when one mode of behaviour is no longer functional and to switch to more functional behavioral solutions (Kelso & Engström, 2006). Such stabilities do not exist a priori in neurobiological structure but are co-determined by the confluence of task and environmental constraints, ideas which are congruent with Gibson’s (1979) proposition that control lies in the agent–
environment system. In this sense behavior can be understood as *self-organized*, in contrast to organization being imposed from within by a hypothesised internal structure. Behavior patterns emerge in the course of learning and development, through a bootstrapping process in which agent–environment interactions give rise to behavioral dynamics. In turn, stabilities in these dynamics capture the behavior of the performer (Warren, 2006). During bootstrapping, the performer actively explores a goal path for a task, both contributing to and locating its stabilities (stable solutions). Reciprocally, attractors in the behavioral dynamics feed back to temporarily fix a performer’s action patterns, in a form of circular causality. Thus, rather than a central controller dictating intended behavior, the agent develops perceptual–motor mappings that tweak the dynamics of the system in which it is embedded so that the desired behavior arises from the entire ensemble. From the performer’s viewpoint, the task is to exploit physical (e.g. surface qualities of the grass field in soccer) and informational constraints (e.g. an opponent’s running speed approach) to stabilize an intended behavior. The emergent solution may rely more or less upon physical or informational regularities, depending on the nature of the task. Within given constraints there are typically a limited number of stable solutions that can achieve a desired outcome. Because cognition is conceived as the ability to use specifying information (i.e., information in the Gibsonian sense) for controlling action, all action involves some amount of awareness, as well as vice versa (Reed, 1997).

In sport, a player’s expertise is only revealed in the consequences of movement and perception embedded in actions, as observable properties of the environment-actor system. Decision making, therefore is a complex, temporally-extended process expressed by actions at the ecological scale (Turvey & Shaw, 1995). This functional analysis of decision making contrasts with traditional approaches in which humans have been modelled as rational decision makers, computing and selecting options from those represented in mental or neural
models designed to maximize utility for performance (Mellers et al., 1998). As Klein (2001) argued: “A decision maker who faithfully follows the rules for estimating expected utilities will not necessarily understand the affordances of a situation and will be less prepared than a decision maker who is studying the opportunities and constraints in the situation” (p.118).

In ecological dynamics the behavior of a performer may have intended consequences for some later time and place beyond the context in which current actions are initiated. Actions (construed as goal-directed behaviours), like perceptions, are intentional because their meaning and significance lie elsewhere from their causal origins. Indeed, “actions are inherently forms of true choice behaviour” (Shaw, 2001, p. 283). Intending a behavioral goal (i.e., a final condition) involves the performer selecting an initial condition as a pathway that permits attainment of the final condition under the existing (physical) law domain. Along the goal path, with each step closer to the final outcome, the information sources detected and used to regulate action must become ever more specific. They are used to narrow the possible actions available for the movement system, until ultimately, at the moment of goal accomplishment, the emergent path becomes uniquely defined (Shaw, 2001), i.e., with fewer degrees of freedom. Given this perspective, decision-making is viewed as a functional and emergent process in which a selection is made among converging paths of actions for an intended goal (see Figure 1). Choices are made at bifurcation points where more specific information becomes available, constraining the environment-athlete system to switch to a more attractive path. In sum, to make decisions is to direct a course of personal interactions with the environment towards a goal, and decisions emerge from this cyclical process of searching for information to act and acting to detect more information.

In such an approach, learning to make successful decisions is concerned with the education of intention, attunement, calibration (Jacobs & Michaels, 2007; Fajen et al., in press) and mastering perceptual-motor degrees of freedom (Newell, 1985; Vereijken et al.,
1992; Savelsbergh & Van der Kamp, 2000). In the next section, we discuss how these learning processes contribute to three possible phases of the development of decision making: i) exploration, ii) discovery and stabilization, and iii) exploitation.

**The development of decision-making skill in sport**

For Gibson (1966) the best way to understand how perception regulates action is by detecting informational constraints specific to goal-paths (Shaw & Turvey, 1999). Goal constraints, compared to physical constraints, can be considered extraordinary (Kugler & Turvey, 1987), taking the form of a rule that indicates how to act if a particular outcome is intended. More to the point, the rule asserts that one should act to change current information, non-specific to an intended outcome, into information that is specific (Shaw & Turvey, 1999). This argument implies that the first step for any learning process to occur is the “education of intention” (Jacobs & Michaels, 2002, 2007), which will initiate the process of exploring degrees of freedom.

These ideas signify that changing constraints shape emerging behavior in dynamical movement systems. It is clear that a particular set of interactions of an individual performer, environment, and task over time can produce a particular function of behavioral change. Newell’s (1986) model describes how emergence in movement system occurs, and it was argued that “the relative impact of these three categories of constraint on the pattern of coordination varies according to the specific situation” (p.354). We can visualise how their relative impact changes with time in Figure 1. Here we can see how constraints can channel the system to define the intended goal path.

**INSERT FIGURE 1 ABOUT HERE**
According to Newell (1986): “Environmental constraints are generally recognised as those constraints that are external to the individual performer. Any constraint on the performer-environment interaction that is not internal to the individual performer can be viewed as an environmental constraint” (p.350). However, task constraints are a specific set of environmental constraints. In this line of reasoning we can consider that the functional constraints (like fatigue; as opposed to structural constraints, like height) of the individual performer, since they are more time independent, are those that should be progressively tuned during decision making training. As Newell (1986) argued “It is clear that a variety of individual performer constraints converge to specify the appropriate pattern of coordination” (p.348, our emphasis) and that “Environmental constraints reflect the ambient conditions for the task, whereas the focus of task constraints is the goal of the activity and the specific constraints imposed” (p.352, our emphasis). So, the more defined the goal path, the more that functional constraints and task constraints specify emergent behavior. In seeking solutions to behavioral task goals, the performer needs to explore and discover the dynamic characteristics of the system, where the system is defined over the individual performer, environment, and task.

**Exploration: manipulating degrees of freedom**

It is clear that many perceptions and actions are possible in any performance situation. In specific performance situations, certain perceptions and actions are more functional than others and, with experience, individuals improve on choosing the perceptions and actions they intend to actualize. Different intentions are presumed to organize perceptual-motor systems differently. The education of intention might have an important influence on which particular informational variable needs to be perceived by a performer.
Intentions depend on multiple factors, such as needs, expectations or beliefs, and also external influences such as instructions, which make it challenging to study sport. Ecological studies often proceed by choosing situations in which a particular intention can be assumed. In a 1 vs 1 basketball game close to the basket, for instance, it can be assumed that attackers with the ball intend to dribble past the defender and to shoot at the basket in order to score, rather than to simply maintain possession of the ball. Such assumptions are necessary to make because intentions constrain tasks, and because assuming a particular intention is required to define and identify what informational variables are relevant at any moment (Jacobs and Michaels, 2007). Given particular intentions, therefore, some variables can be said to be informational and others not.

Bernstein (1967) raised the problem of how to control the many degrees of freedom that characterize motor coordination. He argued that the complex interaction between the different components of the human movement system (e.g., muscles, tendons, joints) make separate control of all these components impossible. Therefore, the large number of individual degrees of freedom to be regulated has to be reduced in order to make control possible. This reduction is a process of “…mastering redundant degrees of freedom of the moving organ, in other words, its conversion to a controllable system” (Bernstein, 1967, p.127). Bernstein’s question, implies that a system with many degrees of freedom can simplify its organisation only if sufficient constraints, or linkages, are established among its components by coupling them into a synergy. The coupling of external, environment-based force fields with internal, performer-based force fields by means of information fields (Kugler & Turvey, 1987) forms the basis of a theory of cognition for goal-directed behavior, and guides the principles for the development of decision-making skill.

When the intention of a performer corresponds to the task goal there is a need to coordinate the redundant degrees of freedom of his/her movement system. There is a need to
establish basic relationships with the environment to acquire minimum control over system
degrees of freedom, both intrinsic and transactional, to realise the task. Sometimes, control
may be obtained by “freezing” solutions (Vereijken et al., 1992; Davids et al., 1999;
Savelsbergh & van der Kamp, 2000), or by increasing variability of the environment-
performer system to find a successful task solution (Araújo et al, 2005). It is not surprising
that different people may rigidly stabilise different solutions (i.e., acquire movement patterns,
and, or, use informational variables) to achieve the same goal. At this stage, movement may
be coupled to a specific information source that is highly functional, although it may not
specify the property of the environment that the performer intended to perceive, i.e., it may
be a non-specifying variable. The term “specifying variable” is used only for a variable that
specifies the property (i.e., the informational variable) that a perceiver intends to perceive
(e.g., the focus of expansion of the ball on a performer’s retina during catching), and the term
“non-specifying variable” for a variable that does not specify the property that a perceiver
intends to perceive (e.g., a player attempting to judge the flight path of a ball from the
deceptive movements of an opponent striking it), regardless of whether a so-called non-
specifying variable might specify other properties (Jacobs & Michaels, 2007). When
performers increase variability in the environment-performer system this is due to the
difficulty in discriminating which properties of the environment constitute information and
which do not. Exploration of what is available in a performance situation can reveal what
environmental properties are informative in relation to a specific intention (Araújo et al.,
2005).

Importantly, the appearance of control over abundant degrees of freedom
characterizes this first stage through the exploration of the relationship between movement
and information. The degrees of freedom that need to be constrained are much more than
those necessary to control the performer-environment system to achieve the task goal.
Discovering solutions and stabilizing them

In the next phase, the performer uses these tentative solutions and attempts to reproduce them when performing the task. With the irreducible variability of the initial conditions to perform the task, movement-information couplings start to become more regular. A way to stabilize a movement solution is to “de-freeze” the previously exaggerated constriction of degrees of freedom. This means that the most relevant degrees of freedom for achieving the task goal are identified. The conditions when an informational variable is useful are also identified and acted upon. Therefore, new action possibilities start to be identified (for example, when an informational variable is not useful). For example, this process can occur in sport when a learner in soccer discovers from proprioceptive feedback that stiffening the muscles of the lower limb is not useful for receiving a pass, but can be a useful solution for making a wall-pass to a team-mate.

During this stage, the same intention might lead to the detection of other variables. The process of attending to more useful variables is referred to as the education of attention, or perceptual attunement (Gibson, 1966, 1979). Thus, even if an intention does not change, with experience, perceivers attend to more useful variables. Perceptual attunement is the process of learning which sources of information to attend to in which situations and when to attend to these variables. With practice, performers converge from sources of information that may be only partly useful in one particular situation (i.e. non-specifying) to sources of information that are more useful (i.e. specifying), under a variety of performance circumstances. For example, ball players learn that it is more accurate to perceive the spatial location of a ball rather than to wait for a coach to tell them where a ball is (the latter may be useful only in certain situations).
The stabilization of discovered solutions, as well as the exploration of the limits of these solutions, and consequent search for new, specifying, information-movement couplings, represent dominant characteristics of this phase.

**Exploiting degrees of freedom**

Specifying information sources tend to be regularly used when performing a task and the fluidity of movement (i.e., the mastering of motor degrees of freedom) appears due to the use of external forces, contrasting with previous opposition to or elimination of these forces. The exploitation of motor and perceptual degrees of freedom allows adaptation to situational demands and effective goal achievement. At this stage there is a manifestation of attunement to wider spatial and temporal variables and more sensitivity to the contextual consequences of one’s actions (Araújo et al., 2005). Although more variability in the action may occur, this variability is constrained and convergent to goal achievement. With regards to studying movement patterning, this process is typically described in the literature as *motor equivalence* (e.g., Hebb, 1949). But these ideas could also be applied to processes of perception and cognition. Degeneracy or the ability of elements that are structurally different to perform the same function or yield the same output may be a more appropriate conceptualisation of this process in different neurobiological sub-systems (Edelman & Gally, 2001; Davids et al., 2006).

A relevant process at this stage is that of calibration, or the scaling of the perceptual-motor system to information. Specifying information can appropriately constrain a perception or an action. Body dimensions and action capabilities are not fixed, but change across both short and long time scales. For example, in racket sports, implements such as racquets alter a performer’s effective body dimensions (reach). Action capabilities change across short time scales as a result of factors such as fatigue and injury, and across longer time scales as a
result of development and training. When body dimensions and action capabilities change, actions that were once possible may become impossible (or vice-versa see Fajen et al., in press). In perception and action, calibration and recalibration are necessary to establish and update the mapping between the units in which the relevant properties of the world are perceived, and the units in which the action is realised. Calibration in practice makes it possible for performers to perceive the world in intrinsic units even after changes in body dimensions and action capabilities. Successful calibration results in judgements that are appropriately scaled to the property to be perceived, independent of which informational variable is used for perception. For a properly calibrated performer, body-scaled and action-scaled affordances can be directly and reliably perceived by simply picking up the relevant sources of information (Fajen et al., in press). Although recalibration occurs quite rapidly, it is likely that continued experience leads to further improvements in calibration.

Importantly the development of decision making is not a normative or homogeneous process, but occurs along a messy, noisy and a nonlinear route, with idiosyncratic manifestations expected to occur (Newell et al., 2003). Also it is worth mentioning that processes like education of intention, attunement, and calibration can occur in all the three phases. Finally, we would like to acknowledge that, learning may benefit from some kinds of enrichment, as discussed in the introduction to this chapter. This enrichment, however, is not of a symbolic type and does not explain the learning process, enrichment merely facilitates learning. For example, an increase in quadriceps muscle mass with training (enrichment of the organism), at a certain expertise level, may facilitate learning to successfully perform long distance ball passes in soccer. Similarly, the transition from playing bare foot to the use of soccer shoes (enrichment of task conditions) may facilitate learning of dribbling skills.
Implications for training

According to the ecological dynamics approach, it makes little sense to tell novices how experts make decisions or to ask them to think like experts (see also Klein, 1997). Rather it seems that the training of decision-making should be based on organizing practice conditions that promote the acquisition of expertise, even in non-experts (Araújo, 2007). Without slipping into the predefinition of the nature of expertise, we concur with Klein’s (1997) view that a better solution is to teach performers to learn like experts, and to gain expertise autonomously when practicing in training sessions or in competitions. The challenge for the coach is the principled organization of the training session including the intervention in the performer to foster decision making skills. However, there is not a general “optimal organization”, since there is no common answer to all practices. The organization of training practices that are useful (i.e., to develop expertise in decision making) is that which is relevant to improve performance of a certain athlete, or groups of athletes, in a certain context learning a certain task (see Davids, Button & Bennett, 2008).

From this perspective, the coach’s task is to identify i) the expertise level of the performer on the task, ii) the functions (goals) to be trained, and iii) the primary constraints (organismic, task and environmental) to be manipulated or taken into account during practice. The next step for the coach is to prescribe a plan about what to do, and when and how to do it, i.e., to organize practice sessions including the interventions with the performer. We argue that a constraint-led approach may be adopted if one wants to develop decision making in sport (see Davids, Button & Bennett, 2008 for a detailed discussion and representative case studies).

Manipulation of appropriate constraints can direct performers to explore suitable movement behaviors, culminating in functional decisions undertaken by the performer. The key to assisting performers in acquiring effective decision making behaviors exists in
presenting the relevant constraints during the three different developmental phases in
decision-making as discussed in the earlier sections.

Understandably, coaches are particularly concerned with manipulating task
constraints, since they are open to control and provide a direct channel to shape the
progression of an athlete. Particularly, a major challenge is to consider the functional
representativeness of training exercises (Araújo et al., 2007), i.e., to evaluate the
correspondence of a performer’s behaviour in training and competition. Rules, instructions
and equipment can be manipulated to narrow the search within the perceptual-motor
workspace such that effective decisions can be made corresponding to functional
coordination of limbs in performance contexts to achieve the set task goal.

Organismic constraints are obviously important, but they should be intimately related
with task constraints. Therefore, interventions may occur by selecting or transforming aspects
of the task in order to facilitate a specific impact on an athlete, for example, to select athletes
differing in height to play 1 vs 1 near the basket in basketball. Also some interventions (e.g.,
induction of fatigue, simulations of stressful situations, inducing changes in emotional state)
may be appropriate immediately before certain tasks, in order to facilitate coping skills in the
athlete. There is abundant research and examples of this kind of intervention in sport (e.g.,
Vealey, 2007), specifically in the development of decision making skills (e.g., Pliske,
MacCloskey & Klein, 2001). These interventions can almost certainly be functional. But
these organismic constraints are only indirectly related to decision making. They are not
directly involved in the process of decision-making during perceptually guided action (see
Van der Kamp et al., 2008). For these reasons we argue that interventions away from a
representative practice task are meta-cognitive, or specifically, meta-decisional, being
particularly useful for reflective performers, or performers with high verbal skills. Meta-
decisional training requires additional training for the transfer of verbal skills to motor skills,
otherwise the enhancement of performance may be based on perceptual judgements rather than actual movement performance.

Finally, environmental constraints cannot be typically manipulated, but they may be taken into account to promote a better adaptation of the performer to the context of the competition. These influences can be social (e.g., Alfermann & Stambulova, 2007) or physical (e.g., Reilly, 2003), and they can be more global (e.g., religion, culture) or more local (e.g., coach’s attitudes promoting ego or task involvement of the performers; Roberts et al., 2007).

**Conclusion**

To conclude, we have argued that effective training of decision making should not be characterised as an association between stimulus and responses constrained by ‘If-then’ rules or verbalizations in the head of the athletes, but rather by a functional organization of practice activities. The focus of practice in sport should be to direct perceptually guided actions of an athlete to the information sources that specify goal achievement. The aim of training is to guide the athlete towards a state where he/she learns like an expert, where he/she can act to discover information to guide action, i.e., by exploring, discovering and exploiting intrinsic and transactional degrees of freedom for successful performance.

**References**


Figure 1 – A scheme that shows that to make decisions is to influence - by educating intention, by attunement, and by re-calibration - the interaction of a performer with environment in a goal directed activity. The closer the performer is from actual performance the more she is sensitive to momentary variations, and the more she is constrained by past events.